OUTLOOK FOR INCREASED ADOPTION OF SMART GRID TECHNOLOGIES IN ADB ENERGY SECTOR OPERATIONS

Smart Grid Task Force

NO. 42

April 2016

ADB SUSTAINABLE DEVELOPMENT WORKING PAPER SERIES

ASIAN DEVELOPMENT BANK

ADB

ADB Sustainable Development Working Paper Series

Outlook for Increased Adoption of Smart Grid Technologies in ADB Energy Sector Operations

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No. 42 | April 2016

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Printed in the Philippines.

Publication Stock No. WPS167981-2

Cataloging-In-Publication Data

Asian Development Bank.
ADB Sustainable Development Working Paper Series No. 42: Outlook for Increased Adoption of Smart Grid Technologies in ADB Energy Sector Operations.
Mandaluyong City, Philippines: Asian Development Bank, 2016.

1. Smart grid. 2. Energy efficiency. I. Asian Development Bank.

Note: In this publication, "$" refers to US dollars.
ADB recognizes "China" as the People's Republic of China and "Vietnam" as Viet Nam.

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ABBREVIATIONS

ADB – Asian Development Bank
AMI – advanced metering infrastructure
AMS – asset management system
BI – business intelligence
BMS – battery management system
CRM – customer relation management system
DAS – distribution automation system
DLC – direct load control
DMC – developing member country
DMS – distribution management system
DRMS – demand response management system
EDM – energy data management
EMS – energy management system
ERP – enterprise resource planning
FACTS – flexible alternate current transmission system
GIS – geographic information system
GHG – greenhouse gas
HVDC – high voltage direct current
ICT – information and communications technology
IEC – International Electro Technical Commission
IEEE – Institute of Electrical and Electronics Engineers
IGBT – insulated gate bipolar transistor
IoT – internet of things
OPGW – optical ground wire
PLC – power line communication
PMU – phasor measurement unit
PSHP – pumped storage hydropower plants
NIST – National Institute of Standards and Technology
SCADA – supervisory control and data acquisition
SCM – supply chain management
STATCOM – static compensator
TOU – time of use
WAMS – wide area monitoring system

EXECUTIVE SUMMARY

Access to affordable and reliable energy supply is a key determinant to ensure inclusive growth and socioeconomic development particularly in the Asia and the Pacific. The need for financial, technical, and institutional support in energy sector development in the developing countries in the region is massive. Most of the energy sector interventions by the Asian Development Bank (ADB) and other development partners in the region are in the power subsector. Provision of clean energy, increased efficiency and reliability, management of environmental impacts, and institutional strengthening are essential elements to ensure sustainable development of the power sector; and to address climate change impacts due to power sector interventions. To this end, development partners have a huge responsibility in steering developing member countries toward the right direction.

Developed countries are implementing large-scale smart grid technologies and many developing countries are also in the process of adopting various smart grid components into their power systems. This paper is the first in a series of papers that present broad outlines of an approach to integrate smart grid components in ADB power sector operations.

Specifically, the paper presents a description of (i) smart grid and its key components based on international standards; (ii) global initiatives and selected case studies on the application of smart grid technologies; and (iii) insights for increased integration of smart grid technologies in ADB's power sector operations.

The adoption of smart grids is evolving. To adopt feasible smart grid technologies in ADB power sector programs, it is envisaged that ADB will strongly liaise with stakeholders in coordination with other development partners to establish policies and regulations for rolling out smart grid projects.

I. SMART GRID: CONTEXT AND ADVANCEMENTS

A. Introduction

Sustainable energy for all is a key focus of the Asian Development Bank (ADB) because it is a vital service in pursuing inclusive economic growth to achieve the vision of an Asia and Pacific region free of poverty. ADB's 2014 Medium-Term Review of Strategy 2020 reemphasizes three development agendas stated in Strategy 2020: (i) inclusive growth, (ii) environmentally sustainable growth, and (iii) regional integration. In line with these agendas, ADB's Energy Policy 2009 concentrates on (i) promoting energy efficiency and renewable energy; (ii) maximizing energy for all; and (iii) promoting energy sector reform, capacity development, and good governance. These form the bases of ADB energy sector operations across its developing member countries (DMC).

ADB's overall energy program has been a key area of support to its DMCs in their efforts to achieve faster economic growth. In 2015, ADB's approved lending in the energy sector amounted to over $5 billion. ADB's clean energy program has made considerable headway in introducing and supporting energy efficiency improvements and clean energy supply capacity in DMCs. In 2015, lending for clean energy amounted to $2.3 billion.

Majority of ADB's operations in the energy sector are in the power subsector. Core power sector problems that ADB has identified in its DMCs include (i) inadequate capacity to meet demand; (ii) poor reliability and efficiency of power supply in some countries mainly due to the use of outdated technologies, aging infrastructure, and lack of investments for power infrastructure development; (iii) slow progress in renewable energy development; (iv) lapses in systematic operation and maintenance of grids; (v) gaps in environmental management of the sector; and (vi) weak institutional structures, capacity gaps, and lack of policies and regulations in sustainable development of the sector. Also, the power sector is in rapid transition, which is a challenge for developing countries to keep pace with. Therefore, huge efforts and investments are needed to address these problems to implement cost-efficient, sustainable development of power systems in DMCs.

Recent developments in smart grid technologies offer technical solutions that address the problems cited above. Smart grid technologies are being applied across power systems, including generation, transmission, distribution, and services and consumption. With the successful and widespread development of smart grids, countries can expect high-quality electric power service, better system reliability, and quality of service. These maximize energy use and energy savings, and enable higher penetration and greater use of renewable energy sources to capture environmental benefits. Smart grids are also an important element for expanding the use of other low-carbon technologies, including electric vehicles. One of the key features of smart grids is they provide consumers and suppliers with real-time knowledge on system performance, energy consumption, and decision making tools that empower stakeholders in providing quality power supply and optimum usage of energy resources.

In the smart grids space, power systems and information and communications technology (ICT) are developing fast. Research and development activities are ongoing across the globe, with wide-scale rollout in developed countries such as in Europe, Australia, Japan, and the United States. International standards and technology road maps have been prepared, and various international forums to bring together smart grid players together are being held. Due to rapid technological developments, demand for quality and reliability, and the need for distributed renewable energy generation, developing countries have no choice other than integrating smart grid technologies in the upgrading and development of their power systems.

Many developed and developing countries are implementing innovative blended solutions either compartmentally or in many instances as pilot projects. Hence, the smart grid universe is adopting localized definitions that suit the context of implementation and smart components. The scope of this working paper series is to initiate a discussion on developing localized approaches leading to a strategic approach to undertake more interventions in integrating smart grid solutions in ADB energy sector programs in its DMCs.

B. Objectives

The objective of this paper is to present an overview on (i) smart grids and their key components based on international standards, (ii) global initiatives and selected case studies on the application of smart grid technologies, and (iii) insight for increased integration of smart grid technologies in ADB's power sector operations.

As the smart grid component universe is vast, rapidly evolving, and application is varied, this paper attempts to introduce the most appropriate components for a broad overview of the solution space and to set the context for ADB to increase the adoption of smart grid technologies in its operations. Some of the salient features of these components will be treated specifically to bring out the niche aspects of ADB's energy sector policy focus on energy efficiency and renewable energy generation.

II. SMART GRIDS AT A GLANCE

A. What is a Smart Grid?

The concept of smart grid is evolving and the smart grid definition and scope varies from institute to institute. The general understanding is that the smart grid is the concept of modernizing electric grids. Different smart grid definitions by several institutions are as follows:

Institute of Electrical and Electronics Engineers (IEEE). Smart grid is a revolutionary undertaking—entailing new communications-and-control capabilities, energy sources, generation models, and adherence to cross-jurisdictional regulatory structures.

(i) Electrical Power Research Institute. Smart grid incorporates ICT into every aspect of electricity generation, delivery, and consumption in order to minimize environmental impact, enhance markets, improve reliability and service, and reduce costs and efficiency.

(ii) International Electro Technical Commission (IEC). The smart grid comprises everything related to the electric system in between any point of generation and any point of consumption. Through the addition of smart grid technologies, the grid becomes more flexible, interactive, and is able to provide real-time feedback. It is an electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers, and those that do both—in order to efficiently deliver sustainable, economic, and secure electricity supplies. A smart grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies to (i) facilitate the connection and operation of generators of all sizes and technologies; (ii) allow consumers to play a part in optimizing the operation of the system; (iii) provide consumers with greater information and choice of supply; (iv) significantly reduce the environmental impact of the whole electricity supply system; and (v) deliver enhanced levels of reliability and security of supply.

(iii) National Institute of Standards and Technology (NIST). Definitions and terminology on smart grid vary somewhat, but whether called "Smart," "smart," "smarter," or even "super smart," all notions of an advanced power grid for the 21st century hinge on adding and integrating many varieties of digital computing and communications technologies and services with the power-delivery infrastructure.

From these varied definitions, smart grid can be defined as a combination of modern power system technologies, power electronics, ICT, services, and regulatory structures, which enable sustainable management of environmental impacts in the power sector. It also covers increased integration of renewable energy; enhanced markets; enhanced efficiency, reliability and security; improved operation; and reduced costs. Smart grid enables consumers to actively participate in the power system not only as consumers but also as power producers with distributed generation and controlling power consumption.

To realize successful implementation of smart grids, the technologies, regulations, and standards should be modernized together with institutional strengthening. Based on IEEE, successful rollout will demand objective collaboration, integration, and interoperability. A phenomenal array of disciplines will be involved, including computational and communications control systems for generation, transmission, distribution, customer, operations, markets, and services provision.

B. Key Smart Grid Components

IEC has identified the following smart grid elements that could intelligently integrate to form a network that will ensure efficiently delivered, sustainable, economical, and secure power supply. Application program interface performs a significant role in facilitating this integration toward developing an innovative service and communication platform enhanced with intelligent monitoring, control, and supervision technologies. Once all the nodes are interconnected, consumers become a key part of this massive network that allows customers to play an important role in optimizing the system operation than conventional power system.

(i) Smart consumption. Apart from the direct savings from reduced energy losses and improved efficiency on load side, smart consumption allows utilities to control consumer loads and consumption patterns as the utility desires (without compromising the consumer comfort), which is called the demand response. Further it allows consumers to voluntarily participate in the system operation by reducing their noncritical loads and better controllability to the system operators. It also links distribution management systems and building automation systems.

(ii) Smart meter. Smart advanced metering infrastructure is an integrated system with communication networks and distribution management systems that enables two-way communication between utilities and customers. This is the interface of the customer to the utility electricity network. Once synched with the smart grid, the total solution links consumers and utilities by providing information on real-time consumption and supply data. Further, consumers can tap web-based solutions to monitor their own consumption patterns and reduce their electricity bills by consuming energy needs during off-peak periods.

(iii) Smart homes. Smart homes are houses equipped with a home automation system that interconnects a variety of controls including lighting, security, appliances, and other devices in a common network infrastructure that also allows it to become more energy-efficient.

(iv) Local production (distributed generation). Local production or distributed generation can provide power onsite. This often includes site or location-specific renewable energy technologies such as wind turbines, solar photovoltaic systems, geothermal energy production, and mini and micro hydro or thermal power plants. These plants are normally with smaller capacities and less centralized than the traditional mass-scale power plants.

(v) Smart generation. Smart generation uses power electronics to control harmonics, fault ride-through, and fluctuating generation from renewables. It helps increase the flexibility of conventional fossil fuel power plants to counter-balance intermittent power generation.

(vi) Substation automation and protection. Being the primary building blocks for any power system, substations are the most critical element of the transmission and distribution system, and provide protection for the power system. Hence, substation automation and protection is the backbone for secure transmission grid operation, where improved protection through modern data acquisition, supervision, and control functions enables system operators to manage the system more efficiently.

(vii) Distribution automation and protection. Distribution automation and protection optimizes a utility's operations and directly improves the reliability of the distribution system. It is required in distribution networks to deploy a large number of smart communication devices scattered over the network in order to automate the network. The design or extent of automation and protection levels depends on their reliability. Advanced distribution automation concepts promote automatic self-configuration features, reducing outage times to a minimum ("self-healing grids"). Distributed energy resources are able to create self-contained cells ("microGrids"), which in turn can help to assure energy supply in distribution grids even when the transmission grid has a blackout.

(viii) Energy management system. EMS is an intelligent platform used to monitor, control, and optimize the performance of transmission systems mainly consisting of load frequency control and economic dispatch controls. These intelligent energy management systems are designed to reduce energy consumption, improve the utilization of the system, improve reliability, predict electrical system performance and faults, and optimize energy usage to reduce cost. Today, customers require an open architecture (e.g., phasor measurements, visualization of the grid status, dynamic network stability analysis) to enable easy ICT integration and better support to avoid blackouts.

(ix) Distribution management systems. The distribution management system (DMS) integrates all the communication-enabled network elements, field equipment, and supporting systems. It is therefore the control center for the distribution grid. This establishes a total solution for the utility to enhance its operations and services for greater observability on the network with the aid of real-time information databases and geographic information systems. In countries where outages are a frequent problem, the outage management system is an important component of the DMS. Other important components are fault location and interfaces to geographic information systems.

(x) Building automation and control system. This system includes the instrumentation, control, and management technology for all buildings, plants, outdoor facilities, and other equipment capable of automation for the energy-efficient, economical and reliable operation of buildings.

(xi) Decision support systems and system integrity protection. This protects the primary equipment (e.g., transformers) from fatal fault currents, and power systems from instabilities and blackouts. System integrity protection schemes will enhance the target of protection devices, and guard primary equipment from fatal fault currents. It helps to avoid uncontrollable chain reactions that are initiated by protective actions and avoids limited load shedding actions.

(xii) Power electronics. Power electronic devices play an important role in improving power system reliability and quality. Power electronic devices are used in energy storage systems, distributed energy generations systems, flexible alternate current transmission system (FACTS) applications, and high voltage direct current (HVDC) transmission. It is an important part of the control mechanisms of the power grid. Systems like HVDC and FACTS enable actual control of the power flow and can help increase transport capacity without increasing short circuit power.

(xiii) Asset management and condition monitoring devices. Asset management and condition monitoring devices can optimize the utilization of assets that help optimize the capital and operational costs of the network without sacrificing system reliability and quality. These systems consist of scattered physical sensors over the network, embedded with communication devices that may share real-time data with the control centers. At the control center back-end, these devices are integrated with software solutions that control the network performance and behavior of its components, harmonizing even with the external conditions like weather.

(xiv) Information and communication technology. ICT is the backbone of the smart grid as it supports the reliable, scalable, and secure transfer of information between system components. In smart grids, the increased use of ICT technologies helps improve the interaction and integration of formerly separated systems. Utilities increase their ability to detect and correct problems in their system resulting in cost and energy savings. However, as ICT is rapidly evolving, this has also become a challenge in the development of smart grids.

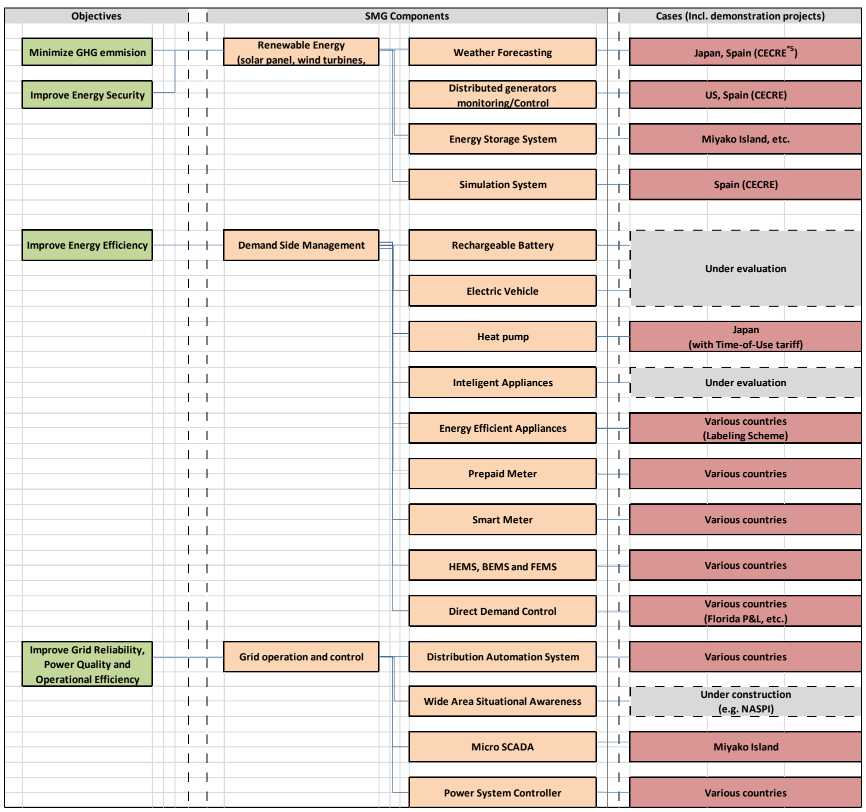
(xv) Security. Since the smart grid is a massive network composed of many devices and entities integrated on to a common platform via a communication link, it is prone to external attacks if the proper security measures are not taken. As smart meters are autonomously collect massive amounts of consumer data, which might be private information that can be used to detect consumer activities, a utility needs to provide a secured communication channel to its consumers.

(xvi) Power quality and power monitoring systems. These elements act in a very similar way to quality management systems in companies. They are independent of operation, control, and management systems and supervise all activities and assets. Therefore such systems can be used as “early warning systems” and are a must to analyze faults and analyze reasons.

III. TECHNIQUES TO INTEGRATE SMART GRID IN ADB ENERGY SECTOR OPERATIONS

Smart grid components as integrated in ADB operations can be mapped into three groups. This grouping acknowledges the diverse universe of smart grid technologies and the objectives of reduction of greenhouse gas (GHG) emissions and energy security by promoting energy efficiency, clean energy development, and improved supply reliability and quality. These groups are (i) smart grid components in renewable energy generation; (ii) smart demand-side management components; and (iii) smart grid operation, monitoring, and control components (Figure 1). Apart from this, as ICT plays an enabling role in efficient functioning of these components, the paper discusses ICT elements as an explicit component.

Figure 1: Mapping of Smart Grid Components



BEMS=Building Energy Management System; CECRE=Control center of renewable energies; FEMS= Factory Energy Management System; GHG=Greenhouse Gas; HEMS=Home Energy Management System; NASPI= North American SynchroPhasor Initiative; SCADA=Supervisory Control and Data Acquisition;

Source: Asian Development Bank.

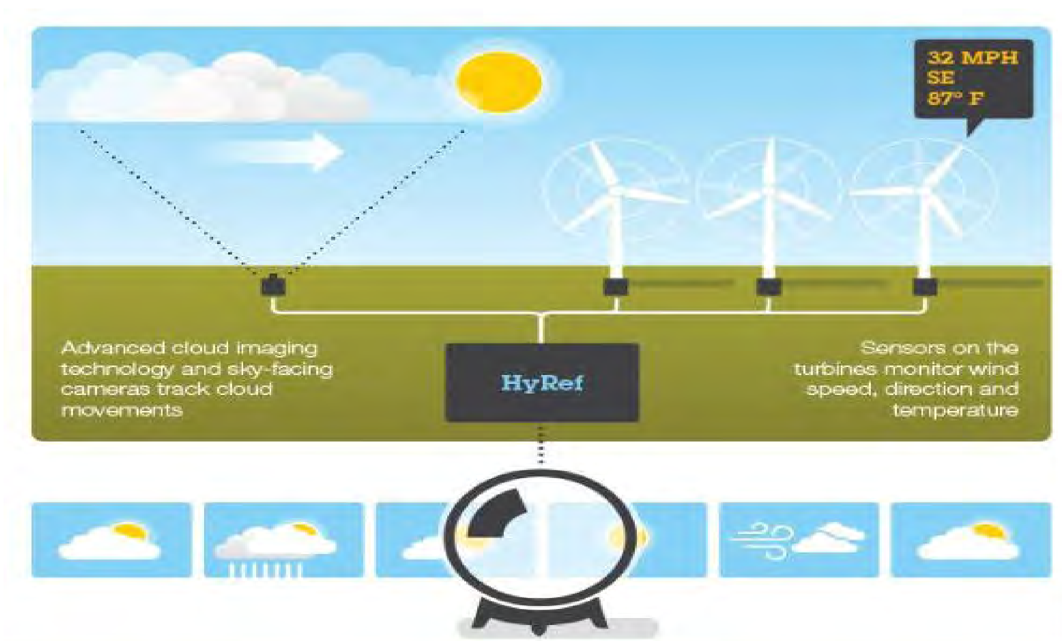
A. Smart Grid Components in Renewable Energy

These are the components that provide solutions to balance the challenges in integrating renewable and distributed energy generation.

(i) Weather Forecasting Systems

Solar and wind-based renewable sources are intermittent in nature, hence predicting their availability is important in optimal usage of resources. Commercial off-the-shelf solutions in advanced power and weather modeling are available, which help in effective integration of renewable energy sources. These solutions deploy cameras, sensors, imaging techniques, and computer-based data and analytics systems to forecast availability of renewable sources and calculate amount of renewable energy that can be generated. For example, International Business Machines (IBM) has developed a hybrid renewable energy forecasting system that uses sensors, cameras, weather models, and satellite images to track cloud movement and wind patterns (Figure 2). IBM's system can predict the local weather up to a month in advance, in 15-minute intervals.

Figure 2: Hybrid Renewable Energy Forecasting System



Source: http//www.engineering.com/ElectronicsDesign/ElectronicsDesignArticles/ArticleID/6580/HyRef-Helps-Put-Renewable-Energy-on-the-Grid.aspx (posted by T. Lombardo. 2013. HyReF Helps Put Renewable Energy on the Grid)

(ii) Energy Storage System

Pumped hydro storage is the most cost-effective, large-scale energy storage scheme at present. Pumped storage hydropower plants (PSHP) pump water up to an elevated reservoir during off-peak hours and generate power during peak hours. It is an effective measure for load factor improvement. In addition, due to fast response to load change, PSHPs can also help control grid frequency and provide capacity reserve. In Japan, the first PSHP was built in 1934. The majority of existing PSHPs were built in 1960–1980, a period when the load factor became very low. At present, over 50 PSHPs are in operation with a total installed capacity of more than 20 GW. With the increased penetration of renewable energy, PSHPs are now considered as an important measure for renewable energy integration. Introducing variable-speed pump-turbines in PSHPs would be one option that gives more flexibility in operation when combined with intermittent renewable generation.

In addition, battery solutions are deployed to (i) regulate the power supply frequency by balancing power supply and demand, (ii) store renewable energy, and (iii) manage capacity by shave or shift peak. Various commercial battery solutions ranging from small 1 kilowatt hour (kWh) to large-scale systems of more than 1,000 kWh are available and being deployed in smart grid projects. Table 1 provides large-scale batteries being used in Japan.

Table 1: Large-Scale Rechargeable Battery Projects in Japan

Company	Battery Type	Energy (kWh)	Capacity (kW)	Date of Commission
Futamata Wind Farm	Sodium sulfur	272,000	34,000	May 2008
Tohoku Electric Power	Lithium ion	20,000	20,000	February 2015
Hokkaido Electric Power	Redox flow	60,000	15,000	March 2016

kW = kilowatt, kWh=kilowatthour.
Source: Asian Development Bank.

(iii) Simulation Systems

The simulation systems in national or regional control centers help in forecasting, controlling, and monitoring renewable energy generation including fluctuation of system parameters such as voltage and frequency. For example, voltage dip analysis is being performed using simulation systems in Spain's control center for renewable energy.[1]

(iv) Distributed Generator Monitoring and Control

Problems in evacuation of renewable energy, in particular solar photovoltaic and wind energy are experienced due to transmission congestion, lack of transmission access, and excess supply during low load periods. Curtailment of variable renewable generation, particularly wind and solar energy, is becoming more widespread as wind and solar energy development expands. Distributed generator monitoring and control systems minimize the curtailment by sending signals in real time to renewable generators via supervisory control and data acquisition (SCADA). Several grid operators in the United States have already installed automated signaling system as shown in Table 2.

[1] T. Dominguez, M. de la Torre, G. Juberias, E. Preito, R. Rivas, and E. Ruiz. 2007. Renewable Energy Supervision and Real Time Production Control in Spain.

Table 2: Summary of Methods Used to Implement Wind and Solar Curtailment

Utility of Grid Operator	Automated Signaling	Manual Signaling (Phone)
Alberta Electric System Operator	x	
Arizona Public Service Company		x
Bonneville Power Administration	x	
Electricity Reliability Council of Texas	x	
Hawaiian Electric Company, Hawaii Electric Light Company, Maui Electric Company	x	
Midcontinent independent System Operator	x	x
NV-Energy	x	x
PacifiCorp		x
PJM Interconnection	x	x
Puget Sound Energy	x (BPA curtailments)	
Salt River Project		x
Tucson Electric Power		x
Western Area Power Administration		x

BPA = Bonneville Power Administration, PJM= PJM Interconnection is a regional transmission organization NV Energy is a public utility which generates, transmits and distributes electric service in northern and southern Nevada

Source: National Renewable Energy Laboratory. 2014. Wind and Solar Energy Curtailment: Experience and Practices in the United States. Colarado.

B. Smart Grid Components in Demand Side Management

Demand side management is the element that supports the efficient management of consumption and utilization of supplied power. The objectives of DSM programs are to avoid or defer capital investment in generation and network infrastructure, with focus on energy efficiency and reduction of GHG emissions. Various technologies have been developed over the years and utilities are continuously adapting to those technologies in DSM. Some of those technologies and approaches form the basis for development of smart grid technologies, e.g., direct demand control, time of use (TOU) tariff, and building energy management systems. Smart grid options and TOU tariff allow customers to reduce use of electricity during peak periods resulting in reduced cost of electricity. DSM sometimes needs to be complemented with policy interventions in the areas of tariffs, incentives, information dissemination and raising customer awareness, and control devices. Some of the smart components that are largely used in DSM are (i) advance metering infrastructure (AMI); (ii) electric thermal storage; (iii) building energy management systems, home energy management systems, and factory management systems; (iv) intelligent appliances; and (v) electric vehicles and plug-in hybrid electric vehicles.

(i) Advanced Metering Infrastructure

Advanced metering infrastructure comprises smart energy meters that can measure two-way power flow, energy usage with TOU, and other system data; communication networks that transmit meter data to the utility; utility information management systems that process the transmitted data; and features to transmit pricing and energy information from the utility company to the consumer. With AMI, utility companies are able to implement a variety of load reduction and energy saving programs, and reduce the cost of providing electricity. In addition, AMI has a wide range of capabilities that can provide significant operational and efficiency improvements. Due to its bidirectional power flow measurement functions, it is possible to measure the distributed energy generation.

The utility benefits from AMI's remote management capabilities such as (i) real-time supervisory control, (ii) remote meter reading, (iii) remote connection and disconnection of services, (iv) possibility of detection of tamper (theft), (v) power outages, (vi) voltage level, and (vii) fluctuations. Smart meters can be postpaid or prepaid meter types. Adoption of prepaid meter is not yet widely seen though it is expected to pick up as it will have a positive impact on energy management of consumers. There are possibilities to simultaneously use prepaid and credit meters as well. Adoption and usage require regulatory changes and consumer awareness. AMI ecosystems are increasingly being used in other utility functions such as commercial and residential water and liquefied gas suppliers. Figure 3 presents some applications of AMI.

Figure 3: Illustration of Automated Metering Infrastructure across Utility Services

Source: PowerCom Americas.

(ii) Electric Thermal Storage

Time of use tariffs have been used in many countries where electricity price in off-peak time is cheaper than the peak time. To take advantage of the TOU tariffs, various types of thermal storage systems have been invented and deployed to supply and store heat in electrically heated houses. This technology facilitates the decoupling of energy production from energy consumption, so that renewable energy can be converted into heat and offering control over when this heat is released. In particular, hot water storage tank systems have been widely used. The system, which consists of a hot water tank and an electric water heater with timer control is quite simple. Energy efficiency of conventional electric heaters is low. To improve efficiency, heat pump water heaters have been introduced to replace traditional electric heaters. Energy consumption of heat pump heater is around one-third that of conventional electric heaters. In Japan, millions of heat pump systems have been installed.

(iii) Building Energy Management Systems, Home Energy Management Systems, and Factory Management Systems

Home energy management systems are devices that are used to control and monitor energy use in the home. These systems offer the ability to switch home appliances on and off. The market for this category is evolving fast in developed economies. Similarly, building energy management systems are computer-based systems used in managing the electrical appliances and equipment used in commercial buildings. Factory management systems are next-generation energy management systems that manage and control energy in a factory both on the supply and consumption side by maximizing the benefits of distributed cogeneration using renewable and natural gas resources. It also utilizes ICT and sensing technologies for visualizing waste generated by facilities, information sharing, and implementing improved productivity through operation-rationalization and labor saving.

(iv) Intelligent Appliances

This emerging technology enables interactive smart grid facility where service providers can control appliances and interact with consumers for management of energy use. Intelligent appliances such as white goods and electric vehicle chargers are being rapidly developed and used.

(v) Plug-in Hybrid Electric Vehicles and Battery Electric Vehicles

Plug-in hybrid electric vehicles are basically about fuel choices and its resultant positive impacts on emission control activities. These vehicles are designed to operate using dual fuel source of hydrocarbon fuels and electric power usually stored in batteries. The batteries can be charged by plugging into an electrical outlet or charging stations. Battery electric vehicles on the other hand run exclusively on electricity via on-board batteries. Electric vehicles include broad automobile variants such as electric bikes, electric trikes, electric buses, and electric cars.

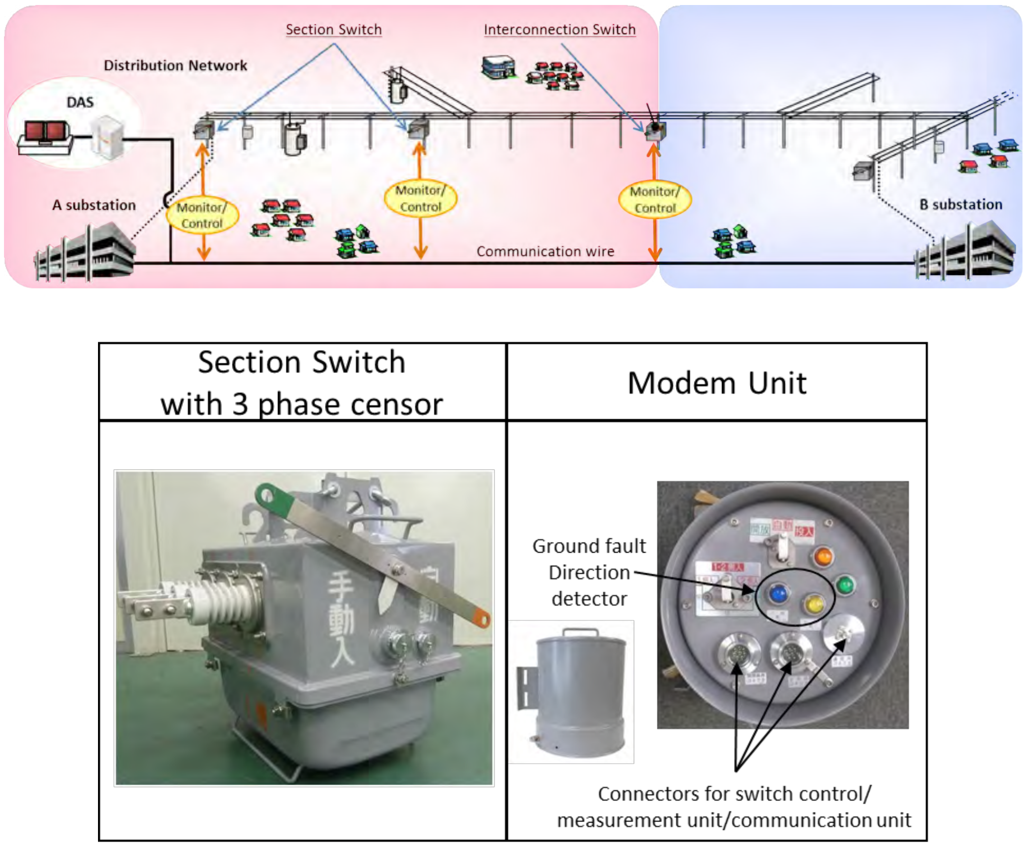
C. Smart Components in Grid Monitoring and Control

Power system monitoring and control plays a crucial role in operation and maintenance of power systems. For increased efficiency, reliability, quality, and flexible operation of power systems, the following smart grid technologies are being implemented.

(i) Distribution Automation System

The distribution automation system is a smart grid component that monitors the status of distribution networks in real time and controls electrical switching devices remotely. Major functions of distribution automation systems (DAS) are (i) automatic fault detection and remote recovery of distribution lines; (ii) real-time data acquisition; (iii) remote control and monitoring of switches; and (iv) load balancing of distribution networks using modern technologies. Traditional power systems use power lines for automated network operations and data acquisition; however, traffic capacity is not enough to transfer real-time technical data (e.g., voltage, current, frequency, power flow, and harmonics). Moreover, it is becoming more important for system operators to make quick decisions. DAS using modern protective equipment with integrated intelligence addresses the real-time data transfer issues and efficient and flexible operation of the networks. The latest DAS have the capability for remote control of section switches (sectionalyzers) with three phase censors, and real-time monitoring of power flow, quality, and faults. Figure 4 shows an example of a latest DAS and a section switch with three-phase censor.

Figure 4: Sectionalizer Switch with Three-Phase Censor and Its Modem Unit



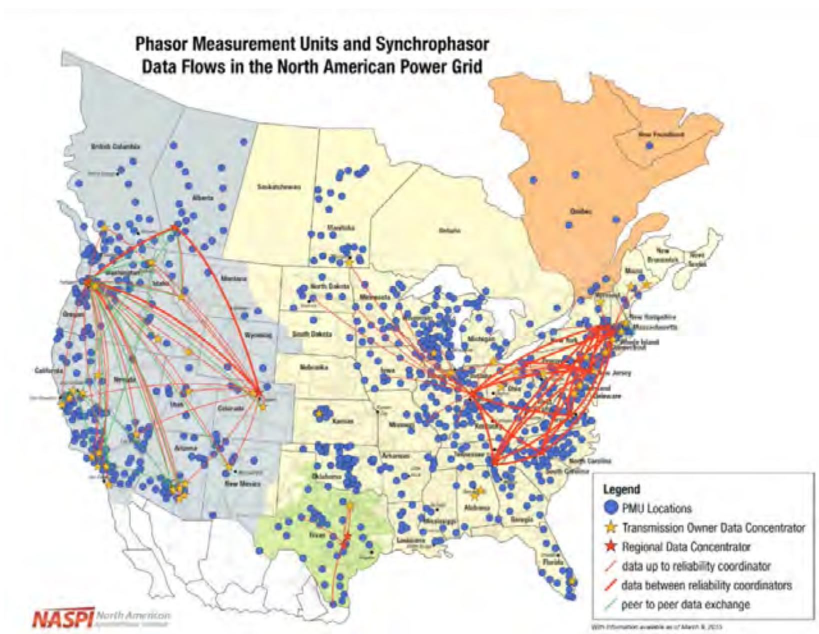
Source: Kansai Electric Power Company.

(ii) Wide Area Monitoring System

Wide area monitoring systems (WAMS) in smart grids support system stabilization to avoid system outages, coordinated voltage regulation, and oscillation damping. WAMS enable right decisions toward faster fault clearances and restoring supply. Supervisory control and data acquisition has been used in power system operations for long. SCADA collects data every several seconds from substations, which enable operators to monitor and control power grids remotely. However, there have been difficulties for system operators in assessing real-time system data using conventional SCADA, in particular data required to assess system stability. This is due to long sampling intervals, data asynchronicity, low precision, and limitations in volume of data that can be measured. Therefore, system operators often carry out offline power system stability analysis in advance, and compute power transmission capacity limits within set operation criteria to make decisions. However, it is increasingly difficult to carry out offline analysis and decision making in the current power systems due to demand for reliability and quality, as well as renewable energy integration, among other aspects. For example some developed countries suffered massive outages in the past because of lack of offline analysis, which could not capture the true status of the gird operation. Challenges in offline analysis are that system operators have to compute the reliability of all combinations of the power system, which is labor-intensive work. Online analysis systems are expected to reduce this workload.

To mitigate these risks, WAMS using phasor measurement units (PMUs) and synchrophasors are used in smart grids and some projects have already been launched, to improve power system reliability and assessment of performance. Synchrophasors assess grid data available from PMUs. PMUs have very short sampling intervals, typically 30 samples per second, over 100 times faster than conventional SCADA technology. Each measurement is time-stamped according to a common time reference such as geographic positioning system. Time-stamping allows measurements from different locations and utilities to be synchronized and combined, providing a precise and comprehensive view of the entire interconnection. Synchrophasor measurements can be used to indicate grid stress, and can be used to trigger faster corrective actions in emergency situations. For example, as of March 2015, there are almost 2,000 PMUs deployed across the United States and Canada. Geographic spread of those PMU locations are shown in Figure 5. However, this technology is still expensive. For example, North American Syncrophaspr Initiative reports that average overall costs per PMU (cost of procurement, installation, and commissioning) range from $40,000 to $180,000. PMU device costs were approximately 5% of the installed cost but cost of other equipment in substations has to be renewed together with communications and high-speed modems.

Figure 5: Phasor Measurement Units—Geographic Spread across the North America



Note: The map does not represent the complete geographic area of US in appropriate scale.
Source: North American SynchroPhasor Initiative (NASPI, https://www.naspi.org/File.aspx?fileID=1514).

(iii) Flexible Alternate Current Transmission Sy stem

The flexible alternate current transmission system (FACTS) devices are based on power electronics technology. These are smart devices that have been developed to control power flow flexibly and quickly to ensure optimal flow, quality, and reliability of power supply. Traditional alternate current transmission systems were not smart enough to ensure optimal power flow. They were not quickly responsive enough to attend to contingency situations in cases of faults, except for transfering power among feeders in the event of faults by switching circuit breakers. It is getting more and more difficult to operate a transmission grid due to the need to ensure efficiency, reliabilty, quality and increased integeration of distributed generation. Distributed generation has changed the traditional load (power) flow profiles. Transmission congestion is one of the major issues faced in most of the developed utilities due to high penetration of renewable energy. Operators cannot redirect power flow to other transmission lines due to the shortage of transmission capacity and paths, and some renewable generators are curtailed due to this reason. Under these circumstances, the FACTS devices have the facility to control both active power and reactive power.

Key technical aspects of FACTS are as follows.

(i) FACTS for series compensation or active power control. Controlling the impedance on a transmission line is one of the solutions for power flow control. Historically, fixed series capacitors have been installed to reduce impedance and improve transmission capacity. To improve power system stability more actively, thyristor controlled series capacitors were developed and are in operation in some countries, e.g., the People's Republic of China and India. These capacitors can improve power system stability by changing its reactance simultaneously.

(ii) FACTS for shunt (parallel) compensation or reactive power control. Reactive power compensation is one of the solutions to improve power stability and grid flexibility. A capacitor bank and reactor bank are widely utilized for this purpose. Rotating synchronous generators are used to absorb and generate reactive power. Although the generators can change reactive power continuously and rapidly even during short circuit faults, unlike a capacitor or reactor bank, they have high power losses and maintenance costs. Due to these limitations, they have been superseded by thyristor controlled static var compensators, which can only generate reactive power. Subsequently, gate turn on/off transistor and insulated gate bipolar transistor (IGBT) were developed as a replacement of thyristor. Static var compensators controlled by these transistors are called static synchronous compensators (STATCOM), which can provide fast voltage support with power systems. The fast voltage support is critical for generators to maintain stable operation during and after a disturbance. A STATCOM system consists of a condenser, converters, and a step-up transformer. As shown in Table 3, STATCOM systems have already been installed and been operating globally for more than 20 years.

(iii) High voltage direct current system. Power system stability sets the limit to the alternating current power transfer. There has been a high demand for bulk power transfer over long distances in certain areas. HVDC, which is a major application of the FACTS device, has been deployed in many countries as one of the best solutions. HVDCs convert alternating current to direct current for transmission at a station, and converts direct current back to alternating current at the other station with FACTS device. HVDC is economically preferable for transmitting bulk power over long distances, typically lengths exceeding 700–800 km. Thyristors have been used as a key device for convertors and invertors in HVDC stations. The Southern Hami–Zhengzhou UHVDC ±800 kV DC transmission system with thyristors was commissioned in 2014 with a capacity to transfer 8,000 megawatts (MW) over 2,210 kilometers (km). In the meantime, development of IGBT has made progress, and several medium-scale IGBT stations are in operation. IGBT can control active power and reactive power independently, which has great advantages to control power system voltage and save costs for reactive power compensation equipment such as reactors and condensers. DolWin1 HVDC system with IGBT went in operation in Germany in 2015, which can transfer 800 MW over 165 km. Total capacity of HVDC in the world reached 90 GW in 2009.

Table 3: Static Synchronous Compensators Details

Year	Company	Location	Voltage (kV)	Capacity (MVar)
1991	Kansai Electric Power (Japan)	Inuyama Switching Station	154	80
1995	Tenesee Valley Authority (US)	Sullivan Substation	161	100
2001	Vermont Electric Power (US)	Essex Station	115	133
2003	San Diego Gas & Electric (US)	Talega Station	138	100
2003	Northeast Utilities (US)	Glenbrook Station	115	150
2003	Kansai Electric Power (Japan)	Kanzaki Substation	154	80
2004	Austin Energy (US)	Holly	138	110
2009	Transpower (New Zealand)	Kikiwa Substation	220	50
2011	Transelec (Chile)	Cerro Navia Substation	220	140
2012	Chubu Electric Power (Japan)	Toshin Substation	275	450
2012	Power Link Queensland (Australia)	Blackwater	132	100
2013	Long Island Power Authority (US)	Holtsville/Wildwood	138	75
2013	Saudi Electricity Company (Saudi Arabia)	Quwayyah Substation	132	170
2013	Kansai Electric Power (Japan)	Inuyama Switching Station	154	130

kV = kilovolt, MVar =Megavolt-ampere reactive, US = United States.

Source: Asian Development Bank.

Currently, greater use of smart grid technologies are seen in smart meters and demand and supply side management, but grid level energy storage components are still lagging.

D. Smart Cities and the Role of Smart Grids

The Asia and Pacific region is experiencing massive urbanization. Urbanization contributes to national economic growth. However, unplanned and unregulated urbanization inflicts heavy stress on urban infrastructure and governance of cities. Urbanization chaos particularly impacts negatively on infrastructure service provisioning capabilities such as electricity, and water and waste management.

Many governments in the region are tackling urbanization effects by undertaking programs such as “Smart Cities”. A smart city uses ICT to enhance quality, performance, and interactivity of urban services to reduce costs and resource consumption, as well as to improve contact between citizens and city governments.

In the context of city governments’ infrastructure services, power infrastructure is one of the main components. Efficiency and manageability of these services is essential to local, municipal, and metropolitan management authorities. Smart grid initiatives directly address the needs of the local government authorities and thus complement the smart city initiatives as far as power infrastructure is concerned. Further, smart grid-based infrastructure can be designed to be coleveraged to other sector initiatives such as intelligent transport management systems, water services management, and disaster management relief and restoration activities.

E. Information and Communications Technology in Smart Grids

Usage of varied data communication methods and distributed computing capabilities supports the intelligence or smartness in power sector operations. The ICT components that are used in smart grids can be classified broadly into communications systems and computer systems.

Communications systems are used to carry power-related data to designated equipment or computing environments. The communications component in power installations comprises data transfer services and integrated communications and computing capabilities.

The data transfer services are generally procured from third party sources. Typical data transfer services commonly employed are internet protocols, electronic business extensible markup language services, frame relays, satellite communication services, microwave services, wireless communication capabilities, cellular and cable communication services, ZigBee systems, and wireless fidelity. These data transfer means are applicable for the power sector providers as well as consumers, meaning a power utility may use some of these communication techniques in the real-time, data-based management of its production and distribution operations as well as bidirectional data communication with and from its consumers.[2]

Generally practiced channels for consumer contact include websites, mobile applications, human–machine interface tools such as interactive voice response systems, speech biometrics, and call center operations. Real-time data gathering from distributed assets and installations of utility providers also uses embedded object techniques. These embedded objects, more colloquially referred to as sensors, are equipped with embedded network connectivity capabilities to receive, process, and send data to codified destinations. This technology capability in modern day communications engineering is referred as “internet of things (IoT)” technologies.

Integrated communication and computing capabilities are electronic or electro-mechanical equipment that have the capability to analyze data as well process them to perform certain codified decisions. The systems that fall in this category include supervisory control and data acquisition (SCADA) systems, FACTS, and WAMS. In some instances, such as optical ground wire and power line communication, components serve only as a conduit to carry data transfer functions and facilitate computing systems to take appropriate real-time decisions.

On distributed computing capabilities, the automation of business processes related to a utility’s operations and efficiency enhancements in service delivery using ICT systems are practiced. Some of the business processes improvement systems are enterprise resource planning (ERP) including billing, personnel management and accounting systems, asset management systems, supply chain management (SCM) systems, etc. These generally fall under the category of institutional systems. In modern information technology industry, concepts like cloud technology and call center based IT-enabled services are being used by the utility companies with third party IT vendors and service providers.

In the context of a smart grid ecosystem, ICT service providers play an important function. The services required from ICT industry are (i) software services; (ii) hardware services; (iii) IT maintenance and production support services; (iv) IT-enabled services for back office administrative support; (v) communication services; and (vi) system integrators to configure equipment to IT interfaces, as well as to provide project management services with respect to ICT activities.

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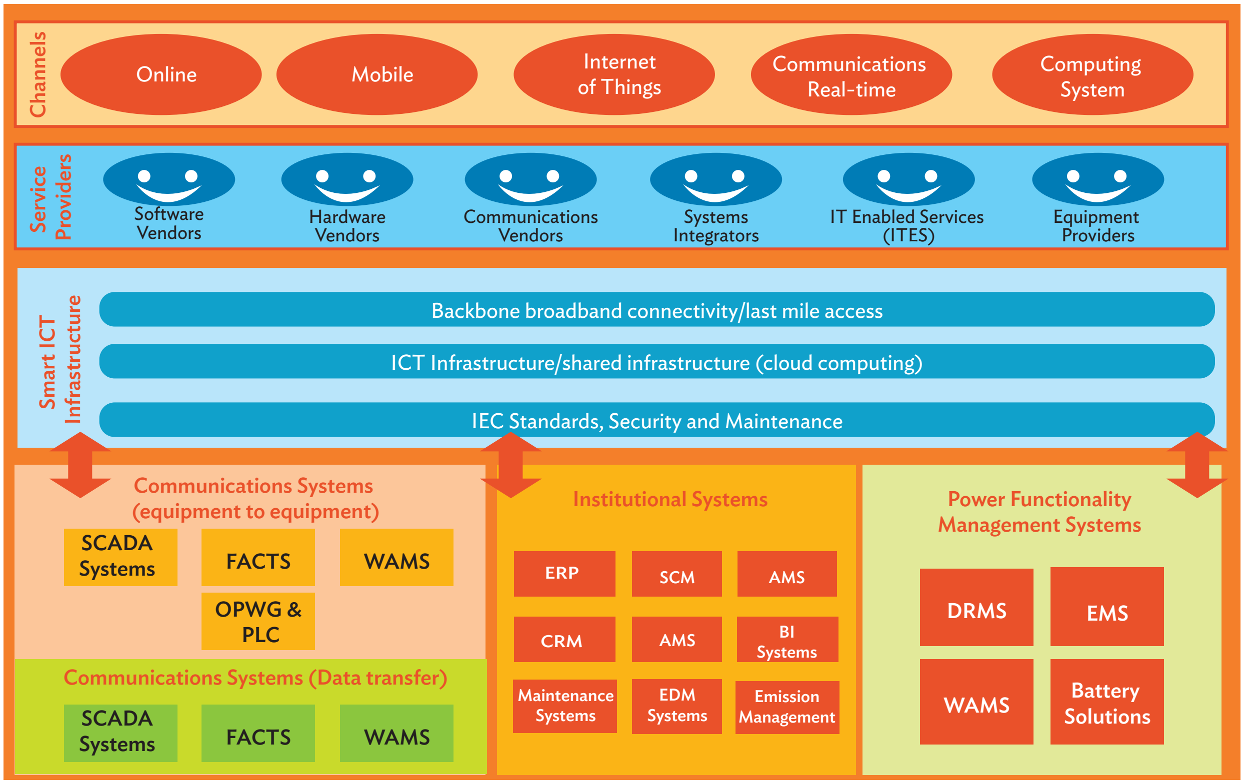
2 N. Cravotta. 2011. Designing Intelligent Appliances for Smart Grid.

Figure 6 represents a view of the ICT ecosystem generally employed in a smart grid activity. The computing and communication components are briefly explained in Appendix 1.

Figure 6: Information and Communications Technology Components in Smart Grids



AMS = asset management system, BI = business intelligence, CRM = customer relation management system, DMS = distribution management system, DRMS = demand response management system, EDM = energy data management, EMS = energy management system, ERP = enterprise resource planning, FACTS = flexible alternate current transmission system, GIS = geographic information system, OPGW = optical ground wire, PLC = power line communication SCADA = supervisory control and data acquisition, SCM = supply chain management, WAMS = wide area monitoring system.
Source: Asian Development Bank.

In smart grid implementation, the factoring in and management of the ICT component is very important. The rapid, changing nature ICT possesses implementation challenges in terms of maintenance and operation of the IT components. Proper engagement and structuring of contracts, tracking, and monitoring of vendor performances with service providers are essential. Further, the strict adherence to standards and enforcement of high cyber security compliance are essential to protect the vital smart grid assets of the economy.[3]

ICT project management capability in smart grid installations are important features that utility providers and government agencies must consider. As technological obsolescence is a rapid feature, techniques to optimize ICT assets efficiently using management tools such as total cost of ownership approaches, continuous improvement initiatives and software quality assurance procedures, ICT procurement and license management, and best ICT architecting capabilities are required.

3 R. J. Campbell. 2015. Cyber Security Issues for the Bulk Power System.

F. International Technical Standards for Smart Grids (Smart Grid Codes)

Grid code development and implementation is a critical area in smart grid implementation. It has to be aligned with the standards being used in respective countries and international standards. This is an important first step in smart grid implementation. Some of the international standards are as follows.

(i) IEEE1547 Family of Standards. IEEE 1547 family of standards deals with smart grid components involving distributed resources interconnection. Released in 2003, this provides the basis and sets the standards for the integration of distributed energy generation by detailing requirements related to interconnection performance, operation, testing, safety, and maintenance.

(ii) IEEE 2030 Family of Standards. The IEEE Standard 2030–2011's "Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System, and End-Use Applications and Loads" is the root standard of the 2030 series. This standard provides alternative approaches and best practices for achieving smart grid interoperability.

(iii) IEC Family of Standards. IEC has identified over 100 standards relevant to smart grids. The following are core standards: (i) IEC/TR 62357: Service Oriented Architecture; (ii) IEC/61970: Common Information Model/Energy Management; (iii) IEC 61850: Power Utility Automation; (iv) ICC/61968: Common Information Model/Distribution Management; IEC 62351: Security; (v) IEC 62056: Data Exchange for Meter Reading, Tariff and Load Control; and (vi) IEC 61508: Functional Safety of Electrical, Electronic, Programmable Electronic Safety Related Systems.

IV. GLOBAL SMART GRIDS INITIATIVES AND CASE STUDIES

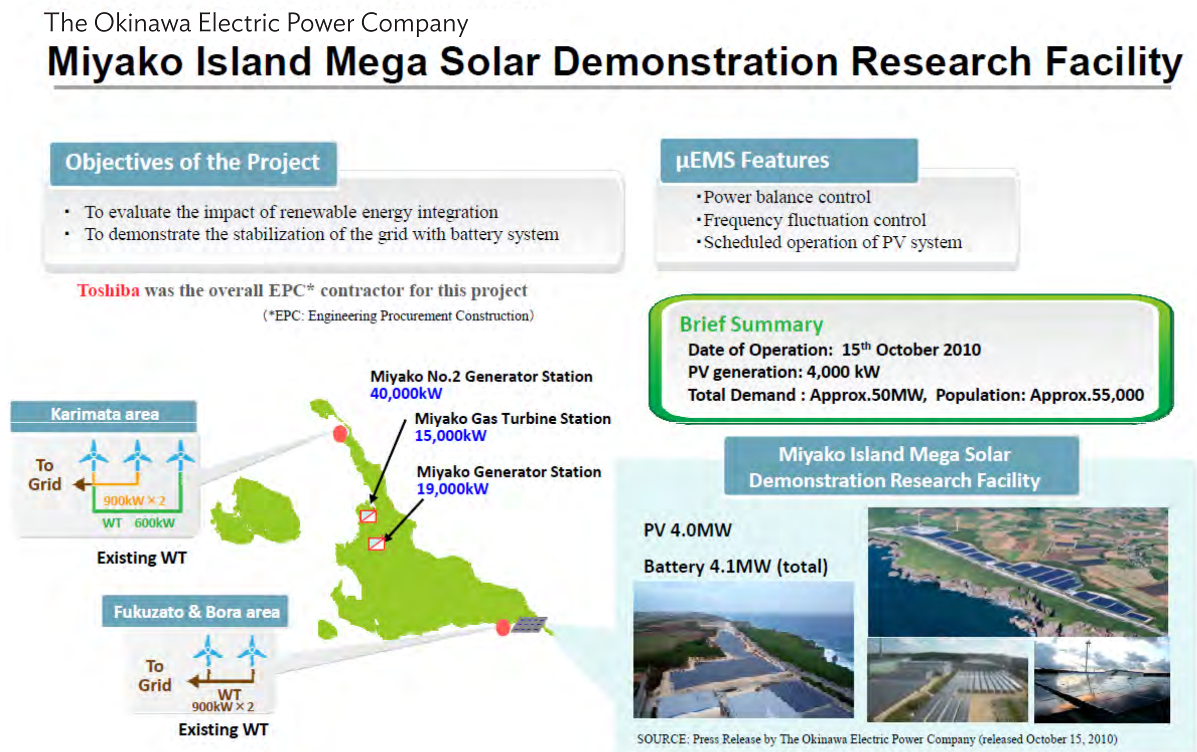
A. Smart Grid Initiatives

(i) Smart Grid at Miyako Islands, Japan

To evaluate the impact of renewable energy integration and to demonstrate the stabilization of grid with battery system, a smart grid project was commissioned in 2010 in the Miyako Islands off the Okinawa prefecture. The smart grid components included features for addressing power balance control, frequency fluctuation control, and scheduled operations of solar photovoltaic systems and wind power plants (Figure 7).

Analysis of the results of implementation of the Miyako Islands project provides insight on two aspects: the need to critically manage the frequency control with batteries used; and implementing effective generator scheduling mechanisms. To maintain frequency within the normal operation range (59.7-60.3 hertz), and to minimize the capacity of sodium-sulfur battery, the frequency response rate of the battery should be 480 kW/0.1 hertz. At this rate, the required battery capacity is approximately 1,200 kW. Energy management systems developed by Toshiba are able to make least-cost daily schedules for generators including batteries. Power supplied by batteries rather than diesel units during peak hours saved fuel cost.

Figure 7: Smart Grid at Miyako Islands, Japan



Source: Smart Grid Progress in Japan & US, Toshiba Corporation, 3 December 2012, http://www.enecho.meti.go.jp/notice/event/036/pdf/event036003.pdf

(ii) Smart Grid at Jeju Islands, the Republic of Korea

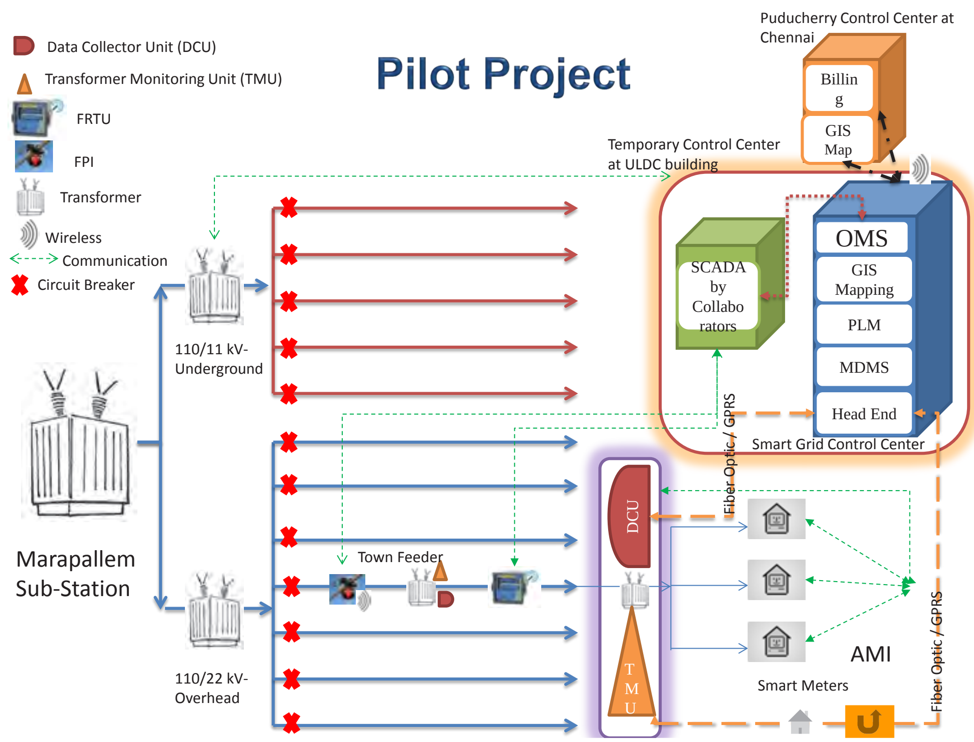
The Government of the Republic of Korea implemented a smart grid demonstration project in Jeju Islands that was focused on five technical aspects: (i) smart transportation, (ii) smart place, (iii) smart renewable, (iv) smart power grid, and (v) smart electricity market. One of this project's targets was to improve energy efficiency by utilizing real-time information of supply and demand. The project outcome in 2012 showed that advance metering infrastructure (AMI) can reduce electricity consumption by 12%.

(iii) Smart Grid Pilot in India

The Power Grid Corporation of India is developing a smart grid pilot project with the Electricity Department of Puducherry through open collaboration. The project is being implemented with the following objectives: (i) indigenization of technology; (ii) common information sharing platform; (iii) scalable replication in other places; (iv) demonstration of effectiveness of each functionality; and (v) development of policy advocacy, regulations, etc. for successful implementation. The pilot is testing smart grid components of AMI, outage management system, (iii) power quality management, (iv) demand response, (v) microgrid, and (vi) energy storage.

The pilot implemented the following attributes: (i) AMI covering energy accounting and audit, load profile, monitoring power quality information and outage data, and tamper monitoring; (ii) virtual demand response covering customer and utility side; (iii) street light automation focusing on energy saving potential; (iv) outage monitoring system dealing with fault passage indicator and automated monitoring distribution transformers; (v) electric vehicle charging through solar photovoltaic systems; and (vi) net metering by renewable integration (solar). Figure 8 provides a schematic presentation of the system.

Figure 8: Smart Grid Pilot in Puducherry, India



Source: Puducherry Smart Grid Pilot Project, Power Grid Corporation of India. 2014. http://www.pace-d.com/wp-content/uploads/2014/04/Puducherry-Smart-Grid-Pilot-Project-PowerGrid.pdf

(iv) Smart City, Malaga, Spain

Endesa's Smartcity Málaga Project is one of Europe's largest eco-efficient city initiatives. It aims to increase energy efficiency, reduce greenhouse gas (GHG) emissions, and boost the use of renewable energy sources. The smart city area at Malaga covers 4 km^2 involving some 11,000 domestic and 1,200 industrial and service customers. A consortium of 11 companies spearheaded by Endesa is rolling out state-of-the-art technologies in smart metering, communications and systems, network automation, generation and storage, and smart recharging infrastructure for e-vehicles. The zone has around 11 MW of renewable generation capacity, which includes numerous roof-mounted photovoltaic installations spread throughout the city, a cogeneration facility, vertical-axis wind turbines and generation systems integrated in street lighting.

B. Case Studies: Demand Side Management

(i) Peak Demand Clipping and Load Factor Improvement, Japan

Japan has limited natural energy resources. Therefore energy efficiency is particularly important and energy utilities in Japan have been working hard to improve load factor levels of the power system. Load factor is the ratio of average load to peak load. Improved load factor means that high cost thermal units could be disconnected during peak time and also GHG emissions could be reduced. During its high economic growth period from 1950 to 1970, the load factor of Japan was around 70%. Later, in the early 1970s, Japan was hit by an oil crisis and the load factor became as low as 60% due to lesser economic activities. Along with the penetration of air conditioners and other appliances, summer became a severe issue. According to Japan Refrigeration and Air Conditioning Association, penetration rate of air conditioners reached 89% in 1998, while the load factor was lowest in the 1990s at 55%. Since then the load factor has been improved gradually to around 65% in 2013.

To improve load factor, Japan developed and promoted various technologies and strategies. Some of those technologies are summarized below.

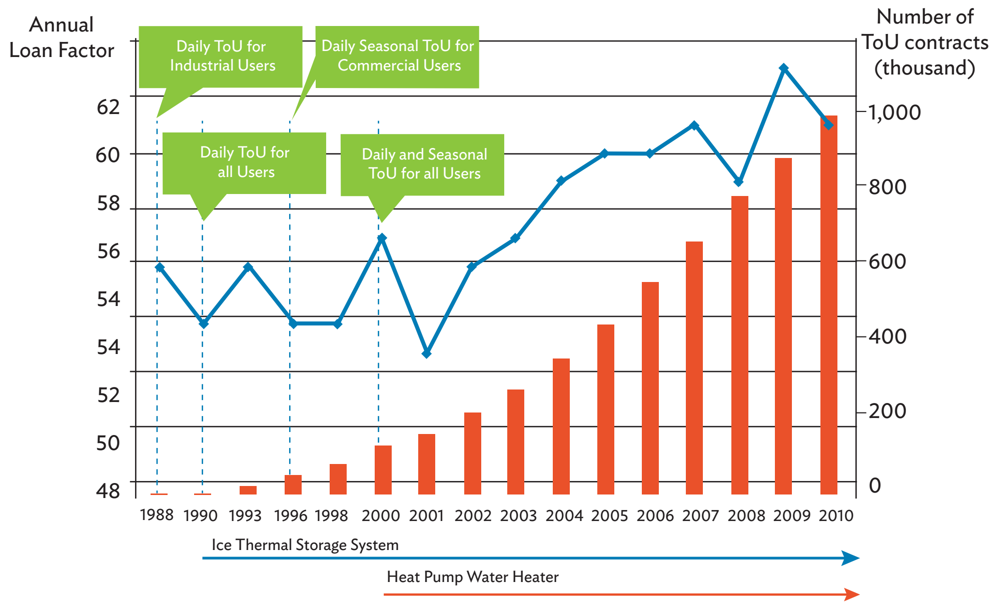
(a) Thermal Storage. Thermal storage is an effective measure to shift load from peak to off-peak periods. A thermal storage system stores thermal energy in the form of hot water, ice, or heat storage bricks during the night and uses the stored energy in the day time. In Japan, the first hot water storage unit was introduced in 1964 along with the first late night tariff. The "on" time was limited to 8 hours during off-peak periods. In 1984, "the second late night tariff" was introduced and the hot water storage unit was modified to a five-hour operation to take the advantage of cheaper tariffs.

Since the mid-1970s, Japan has been developing thermal storage air conditioning systems. Using off-peak electricity, the system makes ice in the summer and hot water in the winter. In daytime, stored thermal energy is extracted for air conditioning. This is a very effective way to reduce peak demand and improve load factor in countries that have seasonal changes.

In 2000, heat pump water heater was introduced to replace traditional hot water units. A heat pump water heater "EcoCute" developed collects heat from the air and a refrigerant transfers the heat to boil water. Heat pump water heaters have much higher efficiency—about three times that of conventional electrical or gas heaters. Therefore, heat pump water heater is considered an effective measure for load management as well as GHG reduction. EcoCute has been supported by the government and utilities and millions of units have been installed across Japan.

(b) Time of Use Energy Meters and Seasonal Tariffs. Off-peak tariff was first introduced in Japan in 1964 to encourage customers to shift their loads to off-peak hours (11:00 p.m. to 7:00 a.m.). In 1970, discount tariffs were developed for thermal storage systems. Later, "the second late night tariff" was introduced with cheaper tariff from 1:00 a.m. to 6:00 a.m. Separate circuits (and meters) are used for metering purposes. From 1988, TOU and seasonal tariffs have been introduced gradually—firstly for commercial customers and then residential customers. The deployment of digital meters made it possible for implementation of TOU tariffs. Since 2000, TOU and seasonal tariffs have been applied to all customers. It has been reported that with the implementation of TOU tariff, sustained improvements in load factors have been observed from utilities. Figure 9 shows improvement of load factor in the areas controlled by Kansai Electric Power, Japan.

Figure 9: Load Factor Improvement of Kansai Electric Power, Japan



Source: Electricity Systems Reform Committee, Ministry of Economy, Trade and Industry, Tokyo.

(iii) Demand Side Management, United States

Power utilities in the United States are generally regulated by each state and most utilities are private companies. From the 1980s, regulators started to mandate demand side management (DSM) responsibilities to power distribution companies. In the United States and also in most of the developed countries, the cost of new programs for improved efficiency, quality, and reliability are generally transferred to consumers through an additional charge on electricity bills. Usually state legislations will set energy saving goals for utilities over a long period (e.g., 10 years). Utilities may undertake DSM programs by internal resource or outsource a third party for implementation. There are established frameworks for program evaluation and verification. Utilities will be rewarded or punished according to their performance. While many of the DSM programs in the United States focus on energy savings, others focus on peak demand clipping.

Typical energy efficiency measures in the United States are in homes (lighting, air conditioning, heat pumps, refrigeration, hot water, insulation); commercial buildings (lighting, air conditioning, refrigeration, hot water, BMS, co-generation); and industrial buildings (lighting, air conditioning, refrigeration, process improvement, BMS, co-generation, high efficiency motors, variable speed drives, and data center management).

Typical peak demand reduction measures in the United States are energy efficiency; fuel switching; load shifting; standby generation; critical peak pricing; and direct load control (DLC) where consumption in hot water, air conditioning, swimming pool pumps, and other appliances are controlled. Some utilities have built DLC infrastructures and developed practical schemes. For example, DLC in Florida Power & Light built DLC using power line communications, which controls 710,000 customers and is capable of reducing 1,000 MW in normal operation and 2,000 MW in emergency. The appliances that are generally controlled in this manner include air conditioners, heaters, water heaters, pool pumps, etc. The DLC system does not require digital or smart meters.

In addition to DSM, utilities in the United States have explored supply-side energy efficiency and demand reduction measures. Voltage control has been implemented and considered effective to reduce both energy consumption and demand. In practice, the system voltages are lowered to the lower limits of regulation to save energy.

It has been reported that significant energy and cost savings have been achieved through DSM schemes in the United States. DSM schemes have also contributed considerably to maintain low electricity prices. As an example, Vermont's "Efficiency Vermont" program targeted residential and business customers. The program provided technical assistance and financial incentives to help customers reduce their energy consumption and cost. For the period 2009–2011, the investments and program achievements are: (i) total investment ($100 million); (ii) total energy savings (304 gigawatt-hours); (iii) peak demand reduction in the range of 13–20 MW; (iv) total benefits ($315 million); and (iv) total carbon dioxide emission reduction of 2,135,000 tons.

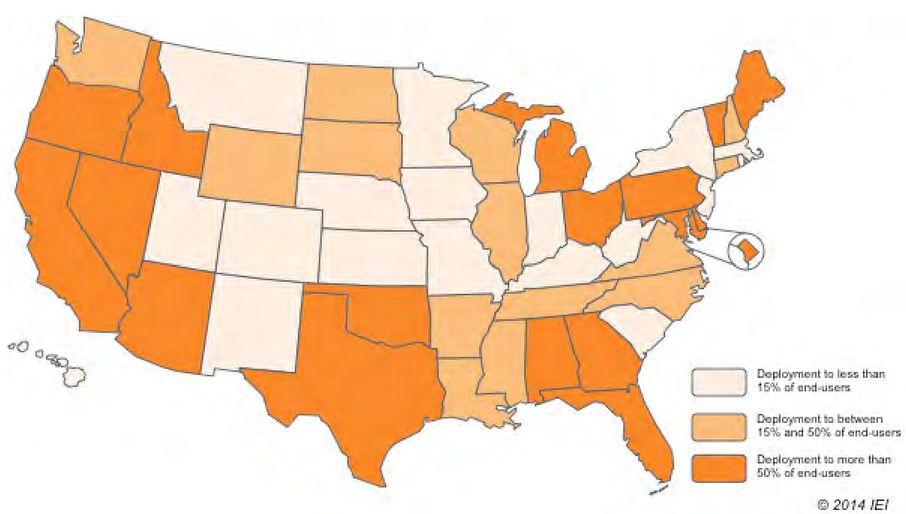
With the development of advanced metering infrastructure (AMI) and other smart grid technologies such as programmable thermostat, energy storage, electric vehicles, it is anticipated that new schemes will be developed and DSM will be able to achieve greater energy and demand savings particularly in the residential sector.

C. Case Studies: Smart Meters

(i) Smart Meters, United States

As of July 2014, over 50 million smart meters had been deployed in the United States covering over 43% of the homes in the country. Figure 10 shows the geographic spread of smart meter deployment in the United States.

Figure 10: Smart Meter Deployments in the United States



Note: The map does not represent the complete geographic area of US in appropriate scale.

Source: The Edison Foundation Institute for Electric Innovation. 2014. Utility-Scale Smart Meter Deployments: Building Block of the Evolving Power Grid. http://www.edisonfoundation.net/iei/Documents/IEI_SmartMeterUpdate_0914.pdf

The Electric Power Research Institute of the Unites States reports that the total cost of AMI deployments for 165 million existing customers from year 2010 to 2030 ranges from $15 billion to $42 billion (Table 4).

Table 4: Advance Metering Infrastructure Cost Assumptions

Residential Meter	Cost
Meter + AMI	$40–$80/unit
Meter + AMI + Disconnect	$70–$130/meter
Meter + AMI + Disconnect + HAN	$80–$140/meter
Commercial and Industrial Meter	
Meter + communications	$120–$150/meter
Installation Cost	
Residential	$7–$10/meter
Commercial and Industrial	$20–$65/meter
AMI network and backhaul equipment	$3–$11/endpoint
Head end software and integration	$4–$10/endpoint
System initiation and management	$2–$4/endpoint
Ongoing maintenance	$3–$11/year/endpoint

Source: Electric Power Research Institute. 2011. Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid. https://www.smartgrid.gov/files/Estimating_Costs_Benefits_Smart_Grid_Preliminary_Estimate_In_201103.pdf

Pacific Gas & Electric reported that deployment benefits from automatic meter reading, operational improvement, demand response, etc., would exceed deployment costs by 4%. However, some state authorities do not impose AMI costs on customers because some customers, such as low-income people and elderly people, do not have much flexibility in electricity usage hence they could not get enough benefits from AMI deployments.

(ii) Smart Meter Deployment in the People's Republic of China

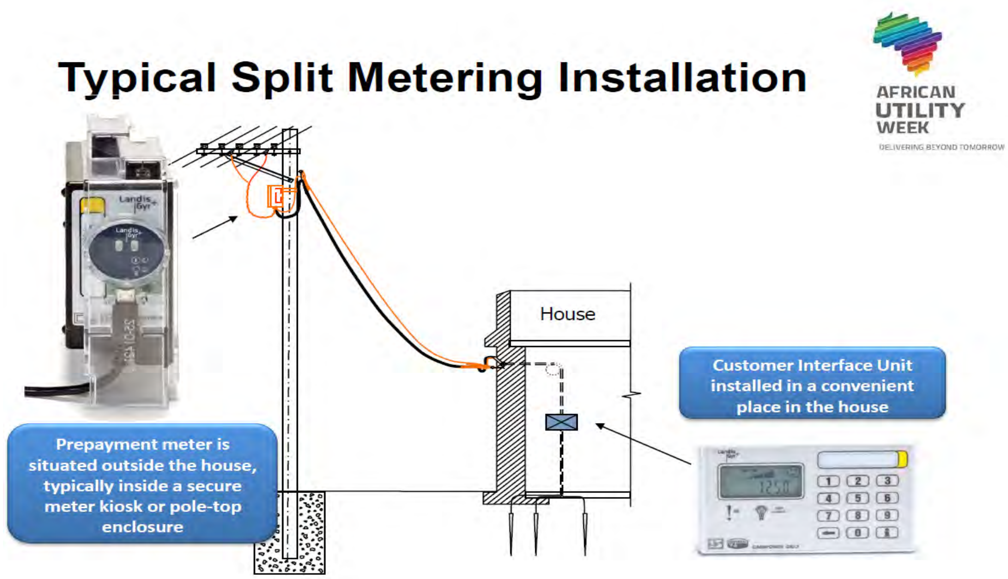
The State Grid Corporation announced a smart grid strategy in 2009 and invited tenders for smart meters in the same year. More than 50 million smart meters had been deployed by 2011. The Corporation has set a target of deploying 230 million more by 2015.

(iii) Prepaid Meter Deployment in African Countries

The first pilot metering project started in 1987 in South Africa and more than 3 million meters were installed by 1992. This implementation provided insights on (i) the need to refine the meter specifications; (ii) reduction in energy usage by 20% due to the introduction of prepaid meters; and (iii) wide acceptance of prepaid meters. Subsequently, in 1993, common requirements for meters and vending systems were published. Also, IEC standards 62055-31, 62055-41, and 62055-51 were adopted. However, it was discovered that loopholes exist such as tampered prepaid meters.

To address this issue and improve revenue protection, second-generation prepaid meters were developed, which consist of two parts, meter and customer interface unit. Figure 11 shows a typical split metering installation where meters are installed outside the house, typically in a street kiosk or pole top enclosure, which would reduce the possibility of customer fraud and tampering. Power line communication is adopted between the meter and customer interface unit.

Figure 11: Split Metering Installation



Source: Landis+Gyr, African Utility Week, 2013 Advance Metering, Cape Town. http://www.landisgyr.com/landisgyr-showcases-smart-metering-solutions-at-african-utility-week

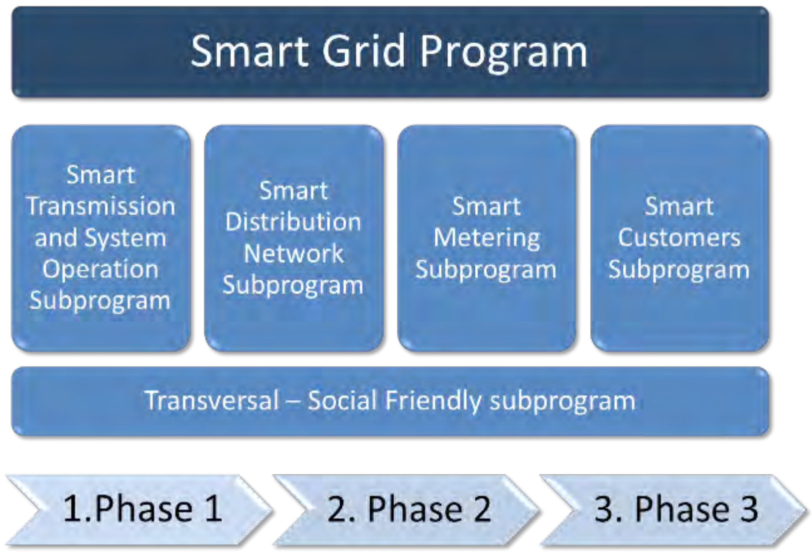
Third-generation prepaid metering systems provide remote monitoring, fraud detection and two-way communication for prepayment meters. Data concentrators with power line communication modems communicate with prepaid meters and communication servers in electric utilities. This system is the same as AMI.

In the case of prepaid meters, customers have to purchase a token in advance. It is inconvenient for them to buy the token at a point of sale. This problem was overcome by adopting mobile phone-based banking. For example, people in Kenya may purchase electricity tokens via mobile banking, e.g., M-PESA. They access the mobile banking site via their mobile phone, and enter their meter number and the amount of electricity token they wish to purchase. They then receive a confirmation SMS that contains the encrypted token number, which is entered into the meter.

D. Case Studies: Smart Grid Road Maps, Viet Nam

Preparation of smart grid options in Viet Nam started in 2011, when the government assigned the Ministry of Industry and Trade (MOIT) to develop a smart grid program. In March 2012 the Electricity Regulatory Authority of Vietnam of MOIT developed a "Smart Grid Project and Implementation Road Map" that was officially approved in November 2012 (Prime Minister's Decision No. 1670/2012/QD-TTg). The road map consists of three phases (short-term, medium-term, and long-term) and covers both transmission and distribution networks. Figure 12 shows the proposed road map at a glance.

Figure 12: Smart Grid Program in Viet Nam



Source: Government of Viet Nam. 2011. Prime Minister's Decision No. 1670/QD/TT on Smart Grid Development. Ha Noi.

The road map implementation is proceeding slowly. Components proposed in each phase are as follows.

(i) Phase 1 (2012–2016)

(a) Enhance power system operation efficiency program: complete the SCADA/EMS project for the National Load Dispatch Center. Install completely the devices to collect operation data from substations and power plants connected to 110 kV grid and above.

(b) Pilot projects: AMI in Ho Chi Minh City Power, grid integration of renewable energy generation in central power corporations.

(c) Building of regulatory framework: load research, load control mechanism, financial mechanism, and regulations for smart grid implementation.

(d) Develop technical regulations: standards for AMI, automation, and tele-control of substations; integration of renewable energy sources and distribution smart grid structure.

(e) Social support program: dissemination of smart grid program for customers and stakeholders.

(ii) Phase 2 (2017–2022)

(a) Continue to enhance the power system operation efficiency program; focus on the distribution network: deploy SCADA/DMS system for the distribution power corporations, deploy the automation equipment for 110 kV substations, and build the smart grid implementation capacities for the distribution power corporation.

(b) Disseminate AMI lessons learned: extend the AMI system to big customers in all power corporations.

(c) Integrate distributed generations, new energy generations, and renewable generations into the network at medium and low voltage: pilot project for smart home, smart city.

(d) Build the regulatory framework for smart grid applications.

(e) Develop the technical regulations: standards of energy storage, smart appliances.

(f) Continue the social support program.

(iii) Phase 3 (2022 onward)

(a) Continue the ICT infrastructure installation program for distribution network: Deploy the SCADA/DMS system for all provincial and/or district power companies to reach an efficient number of medium voltage and low voltage substations; develop AMI system for residential customers, provide customer the opportunities to trade on the retail competitive market; continue encouraging the introduction of distributed generations.

(b) Implement smart grid applications that allow electricity demand-supply balancing in customer level (smart homes) with their own renewable energy sources: use of renewable energy widely in distribution grids with a time of use electricity price mechanism associated with retail competitive power markets.

(c) Build a regulatory framework that allows deployment of smart grid applications based on the existing information technology infrastructure.

E. Research and Development: Smart Grid Testbed in Jeju Island, Republic of Korea

The Republic of Korea's state-run transmission operator, Korea Electric Power Corporation (KEPCO) has set a goal of establishing a national smart grid by 2030. In order to achieve this goal, the company has successfully built and operated a smart grid test-bed complex on Jeju Island focused on improving power system efficiency and developing output-stabilization technology for renewable energy.

Jeju Island is an ideal project area because it is served by a self-contained grid. As well, it was the only site for the company's installation of smart meters, intelligent power transmission and distribution equipment, and configuration of digital transformation systems, which were undertaken in late 2011. Currently it is introducing a real-time pricing system and has installed an electric vehicle charging station, enabling the company to study integration of renewable energy generation and electric vehicle operations into the power network.

KEPCO is focused on four key areas: peak load reduction, reduction in power transmission and distribution losses, integration of renewable energy into the grid, and strategies to reduce the number and length of blackouts. The Jeju Island test-bed results have led KEPCO to explore new opportunities in overseas markets, offering tailored package products combining standard technologies with intelligent electric power options and business models.

F. ADB-Supported Smart Grid Projects

ADB is massively stepping up its effort to tackle climate change in the region, pledging to double annual spending to $6 billion a year by 2020. Table 5 captures smart grid projects financed by ADB in the past 5 years.

Table 5: Smart Grid Components in ADB Operations

Title	Country	Outputs	Financing	Project #
Developing Smart Grid Technology for Efficient Utilization of Renewable Energy	PRC	Road map for wind power integration Technical standards to be met by different types of wind power A regional wind power forecasting model based on numerical weather forecasting data using both historical data and physical characteristics of individual wind farms	$1,200,000 (technical assistance grant)	43053-012
Advanced Electricity Metering Project (Phase 1)	Uzbekistan	Installation of modern, accurate, theft-proof digital meters for 1 million residential and small commercial power users in the cities of Bukhara, Jizzakh, and Samarkand	$150 million (loan)	41340-013
Advanced Electricity Metering Project	Uzbekistan	Continuation of installation of AMI in Andijan, Fergana, Kashkadarya, Namangan, and Surkhandarya	$300 million (loan)	41340-015
Green Energy Corridor and Grid Strengthening Project	India	Real-time measurement and monitoring equipment 800kV HVDC terminals 320kV HVDC terminals	$500 million (sovereign) and $500 million (nonsovereign) loans	44426-016
Preparing Outer Islands for Sustainable Energy Development (Phase 1)	Maldives	Design and Installation of equipment for solar-diesel hybrid grids with rechargeable battery on about 160 islands	$124 million (loan)	46122-003
Second Power Distribution Enhancement investment Program (Tranche 1)	Pakistan	The investment program's objective is to introduce AMI in Pakistan's different DISCOs There are nine DISCOs in Pakistan and the AMI roll-out to these DISCOs will be in phases	$380 million (OCR) $20 million (ADF)	47190-003

ADF = Asian Development Fund, AMI = advanced metering infrastructure, PRC = the People's Republic of China, DISCOs = distribution companies, HVDC = high voltage direct current, OCR = ordinary capital resources.

Source: Asian Development Bank.

V. CHALLENGES IN THE ROLLOUT OF SMART GRID COMPONENTS

There are many barriers in harnessing smart grid technologies in DMCs. One is the affordability of initial investment and operation costs of the smart grid equipment, which cannot be afforded by most DMCs, and suppliers of which are limited. Investments are not financially and economically viable due to high costs of equipment and low tariffs in DMCs, and there are failures in pilot projects. There is a need to develop ICT infrastructure. However, there is also a paucity of government initiatives, policies, and regulatory frameworks; as well as a lack of technical knowledge and experience. Therefore, ADB and other development partners have a big responsibility in supporting DMCs to address these constraints.

The scale of smart grid implementation is significant in advanced economies as they have been developing technologies and have benefited from evaluation of these technologies through pilots and demonstration projects. Technologies are coming to the market at a very fast rate and it is difficult for developing countries to keep pace due to their other priorities. Undertaking smart grid adoptions in a larger scale provide leverage in economies of scale as well as optimization of resource utilization. However, it is very important to plan the smart grid adoption in a systematic manner factoring in financial, technical, and institutional requirements. With regard to the proven technologies, developed countries have faced the challenges and lessons learned over the years can be adapted by the developing countries to their context.

Some of the important first steps in smart grid implementation are preparation of smart grid road maps, capacity building of staff of government and energy sector entities, adopting smart grid codes, and undertaking consumer engagement in a structured manner. A strong push by governments for an integrated approach to smart grid development is essential. In this approach, modernizing power infrastructure to be compliant with green economic requirements, and enabling energy access to all as envisaged in the United Nations' new Sustainable Development Goals for 2016-2030, are required. Also needed are enhancement of efficiency in the energy sector as well as undertaking proper planning and coordination with other infrastructure agencies such as transport, communication, and urban development.

On the soft side, it is essential to involve civil society in implementation, which has a direct bearing on end users. Adequate engagement, communication, and awareness raising activities involving community at large are required.

Management of the ICT component needs to be given important consideration. Project management involving management of ICT installations and technical components in a cost-effective way entails adopting the best ICT architectural standards. Technical management is exemplified by cyber security, given that industrial control systems of crucial infrastructure of national importance are now increasingly integrated with ICT technologies. Power production and flows on the electric grid are increasingly controlled remotely through ICT interfaces. These points of access to vital infrastructure need to be protected from cyber-attacks such as hacking and computer virus attacks.

VI. WAY FORWARD FOR ADB

Adoption of smart grid technologies is important for increased energy efficiency and renewable energy integration; and to provide quantitative and qualitative power supply, which are in turn key for sustained inclusive economic growth and mitigating climate change impacts arising from power sector operations. Short-term smart grid implementation needs are discussed in this paper, as well as long-term measures of scaling up ability for massive adoption of renewable sources, which is mandatory for energy security.

ADB and other development partners have been responding by developing solutions that factor in smart grid components appropriate to and required by DMCs. ADB should take the lead in strategic guidance of DMCs in deploying proven smart grid technologies in the three areas discussed in this paper: (i) renewable energy integration; (ii) demand side management; and (iii) grid operations, monitoring, and control.

In this regard, near-term priorities are as follows:

(i) roll-out of smart meters,

(ii) technologies for integration of renewables,

(iii) demand side management,

(iv) transmission and distribution grid modernization,

(v) deployment of energy storage solutions,

(vi) micro grids, and

(vii) development of ICT architecture with particular emphasis on cyber security.

On the soft side, ADB should support the development of smart grid road maps, capacity building, formulation of policy and regulations, and standardization. In this regard it is proposed to undertake the following smart grid activities in a stratified manner for the short, medium, and long term.

(i) Phase 1 (1–2 years)

  (a) Design the grid up to 2030 (long-term planning, modern planning techniques, bottom-up approach).

  (b) Analyze the context in each of the DMCs and develop country-specific grid modernization road maps.

  (c) Develop smart grid codes, policies, and regulatory incentives to allow smart grid transition.

  (d) Identify proven smart grid technologies, including strategies from completed smart grid projects across the globe, then develop smart grid pilots and projects for DMCs.

(e) Integrate smart grid components in grid development projects.

(f) Share knowledge, and enhance institutions and capacity of grid operators and managers.

(ii) Phase 2 (up to 3 years)

(a) Roll out proven smart grid technologies in all the grid development and upgrading projects.

(b) Develop appropriate ICT architecture.

(iii) Phase 3 (up to 10 years)

(a) Scale up implementation of smart grid projects.

(b) Adopt smart cities integrating multiple sectors.

APPENDIX 1

DESCRIPTION OF INFORMATION AND COMMUNICATIONS TECHNOLOGY COMPONENTS IN SMART GRIDS

A brief description of the components of smart grids in the context of the energy sector is provided below. Some of the components such as enterprise resource planning (ERP) systems and supply chain management (SCM) systems are generic and used across multiple sectors, but their application is customized to the specific sector. In the context of this paper, the generic information and communications technology (ICT) solutions represent customized adoption in energy sector activities.

(i) Enterprise Resource Planning System

Enterprise resource planning (ERP) ICT systems refer to a software solution suite that caters to business management of energy and utility companies to optimize their operations. ERP typically comprises modules such as financial management, integrated budgeting and forecasting, personnel management, and revenue management. Some ERP systems also handle inventory management and asset management features. Typically these are developed as home-grown systems in utility companies. Today, the solution is offered as a service using cloud technology concepts. This mode is applicable to almost all the commercially available off-the-shelf ICT components.

(ii) Supply Chain Management System

This ICT system offers solutions in the space of optimizing supply and demand associated with energy production and distribution, transportation logistics, equipment, and emergency service management. The system's functionality will vary across different types of energy sources. For example, oil- and gas-based energy utilities will have information specificities associated with oil and gas intricacies such as piped supply and associated geographical information. A coal-based power plant may have transportation logistics tied with transport vendors.

(iii) Forecasting and Business Intelligence Analytical System

This system provides analytical capabilities to users; the kind of information that can be sliced and diced into various types of dimensions and facts. The system stores codified forecasting techniques and builds a model that is applicable to the user's context. Further, the system receives various data feeds from internal and external sources and enables real-time slicing and dicing of data to make decisions.

(iv) Asset Management System

ICT asset management systems generally store details related to various energy assets of the company. They have capabilities to store maintenance history, maintenance schedule, and life and performance history of numerous assets of the company to manage assets efficiently. In the case of electric network operators, effective and efficient asset management is essential for grid reliability.

(v) Emission Management System

Emission management systems are ICT systems that gather, analyze, document, and visualize energy data for regulating and monitoring energy consumption in plants and buildings. It helps in planning energy consumption and setting targets. It also supports linking data on energy consumption to production data, monitoring performance through dashboard systems.

(vi) Energy Data Management System

Energy data management (EDM) systems are ICT systems that collect and analyze data from various sources and output them as reports, which then become bases for regular interventions in the energy system. The system follows requirements stated in ISO 50001:2011 standards.

(vii) Predictive Maintenance System

Networks, connected devices, and data systems are sources for predictive management systems. Also, data is sourced through sensors implanted in machinery and equipment. The infrastructure of data and data-driven intelligence is also referred as the Internet of Things (IoT). According to Gartner IoT is a network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment. An IoT infrastructure monitors equipment across a plant. Data and information can then be fed to plant managers and operators to shift to a predictive maintenance plan in their plants.

(viii) Supervisory Control and Data Acquisition System

Supervisory control and data acquisition (SCADA) systems are the nerve centers of smart grids in distribution automation. SCADA receives stream of data from line sensors and other connected equipment. The data is analyzed and decisions such as regulating voltage levels, optimizing efficiency, routing, and generation are automatically made and executed. SCADA systems in one form or another were being employed since the 1960s. Initial variants operated on a non-real time basis and relied on mainframe system for computing. Further decisions were made on a human-machine interface method. Later PC versions emerged that used LAN architecture. Modern SCADA use internet architecture. Next-generation SCADA will rely on cloud computing to have the processing power necessary to analyze large streams of data from thousands of sources from large grids. The more sources of information the SCADA processes, the more precise optimization decisions become.

(ix) Flexible Alternate Current Transmission System

The present trend of integrating renewable energy sources with traditional energy distribution networks has led to issues of maintaining system stability, power supply quality, and reliability. The network requires flexible operation with minimum losses and cost. Since deployment of transmission infrastructure is capital-intensive, one of many cost-efficient methods is to use the existing lines to their maximum thermal limit. This requires optimum sharing of power flow in these lines. FACTS, such as static compensator (STATCOM), and unified power flow controller are key technologies employed for optimizing power flow in lines. These enhance controllability of transmission networks and maximize power transfer capability. A smart grid uses them together with communications and computing techniques to adaptively optimize the distribution of power flow in the existing lines.

(x) Wide Area Measurement System

Monitoring and control of grid operations and equipment are enabled by automation systems such as SCADA. SCADA measurements are typically processed and communicated once every two seconds. However, the monitoring and control requirement for observability of complex interconnected power networks demand more agile situational awareness capabilities. Small disturbances in these power delivery systems, if not detected early enough, lead to widespread cascading failures in the grid. Wide area measurement systems such as phasor measurement units (PMUs) help in achieving wide area situational awareness by enabling the utility provider to understand the current environment and anticipate future problems with appropriate actions. PMUs allow more granular collection of important operational data to provide a high-quality view and control of the power system as it responds to supply and demand fluctuations. A PMU at a substation measures voltage and current phasors at very precise synchronization with microsecond accuracy, and computes mega volt ampere reactive power and frequency. Measurements from PMU are reported at the rate of 20–60 times a second, which are very useful in tracking grid dynamics in real time.

(xi) Geographic Information System

Geographic information systems (GIS) are part of electrical installation that provide real-time location and associated geographical information to the control centers. They are deployed in conjunction with systems such as SCADA and WAMS. Further, utilities rely on GIS to manage assets, outages, and mapping locations of overhead and underground circuits.

(xii) Automated Meter Reading System

Automated meter reading systems enhance data quality of tracking and monitoring of consumption patterns. Meter readings are continually updated on a central database on a defined frequency. The energy management software uses this data and produces analytical reports. Data collection methods use communication protocols such as short message services, network (TCP/IP), low radio powered, and hard wire.

(xiii) Optical Ground Wire and Power Line Communication

An optical ground wire is a type of cable that is used in the construction of electrical power transmissions and distribution lines. Such cables combine the functions of grounding and communications. The optical fibers within the cable are used for the purposes of high-speed data communications, either for the utilities' own purposes; or they may be leased or sold to third parties to serve as high-speed fiber interconnection between cities. A programmable logic controller is an industrial computer control system that continuously monitors the state of input devices and makes decisions based on a custom program to control the state of output devices.

(xiv) Customer Relation Management System

Customer relation management systems for an ICT suite of products enable management of networks and relationships. These serve as knowledge repositories that enable business continuity in terms of tracking and recording various business interactions and different contexts. Further, the system has the ability to combine information from multiple institutional systems such as invoice data, product master data, and quality assurance data to present holistic information to marketing and sales professionals of the utility.

(xv) Call Center

Call centers are extended organization units of the company. They are generally outsourced to third party vendors. Some organizations provide this as an in-house organizational entity as well. Call centers provide customer service by directly engaging with customers using virtual modes. Call centers also deal with back-office processes involving customer services. Automation is a key enabler in call center operations. For example, the self-service functions related to viewing and paying bills online, checking balances, and signing or renewing services are some of the functions processed by call centers supporting utility operations.

(xvi) Faults and Complaints System

These are software application systems that are used by utility companies to raise, track, and monitor status of implementation of solutions pertaining to faults and complaints received from customers. They are sometimes part of a customer relation management module, and in some instances, are managed as part of a company's back-end process such as call centers.

(xvii) Demand Response Management System

This system is a software platform that allows utilities to manage all aspects of the demand response program through a single integrated ICT system. The information is used in an intelligent and efficient way for planning and executing load shed at grid locations where the utility can reap more benefits.

(xviii) Distribution Management System

This software system is used in improving the reliability of the power distribution system. It identifies troubled energy assets and takes action to improve network performance. A typical use of this system is in fault detection, isolation, re-route determination, and restoration.

(xix) Energy Management System

This is a specialized computing ecosystem comprising software, hardware, and communications platforms used across the power grid to increase the use of existing electrical capacity and alternative energy sources such as wind and solar. For example, wind guide vanes use technology to optimize their position as wind conditions change.

(xx) Battery Management System

A battery management system (BMS) is a group of software components embedded in the battery management controller and cell management controller module of the battery system. It is used in electric vehicles, as well as plug-in hybrid and hybrid vehicles. BMS manages a rechargeable battery unit by protecting the battery from operating outside its safe operating area, monitoring its state, calculating secondary data, reporting data, controlling its environment, and authenticating or balancing it by collecting and processing data such as temperature, coolant airflow, current, voltage, and state of charge. The BMS relays data to external equipment through wireless communication protocol or serial communications protocol.

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Outlook for Increased Adoption of Smart Grid Technologies in ADB Energy Sector Operations

The working paper presents an overview of technical and functional details on smart grids to provide a framework for increased integration of the technology in ADB's Energy Sector operations. The paper proposes support in development of smart grid road maps, smart grid codes, policies and regulatory frameworks, capacity building, and implementation of smart grid projects in a phased manner.

About the Asian Development Bank

ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to the majority of the world's poor. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

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