A.1 Smart grids[i]

1. Introduction

The US Department of Energy (DOE) defines smart grids as follows:

"Smart grid generally refers to a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation. These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries. They are beginning to be used on electricity networks, from the power plants and wind farms all the way to the consumers of electricity in homes and businesses. They offer many benefits to utilities and consumers -- mostly seen in big improvements in energy efficiency on the electricity grid and in the energy users' homes and offices."

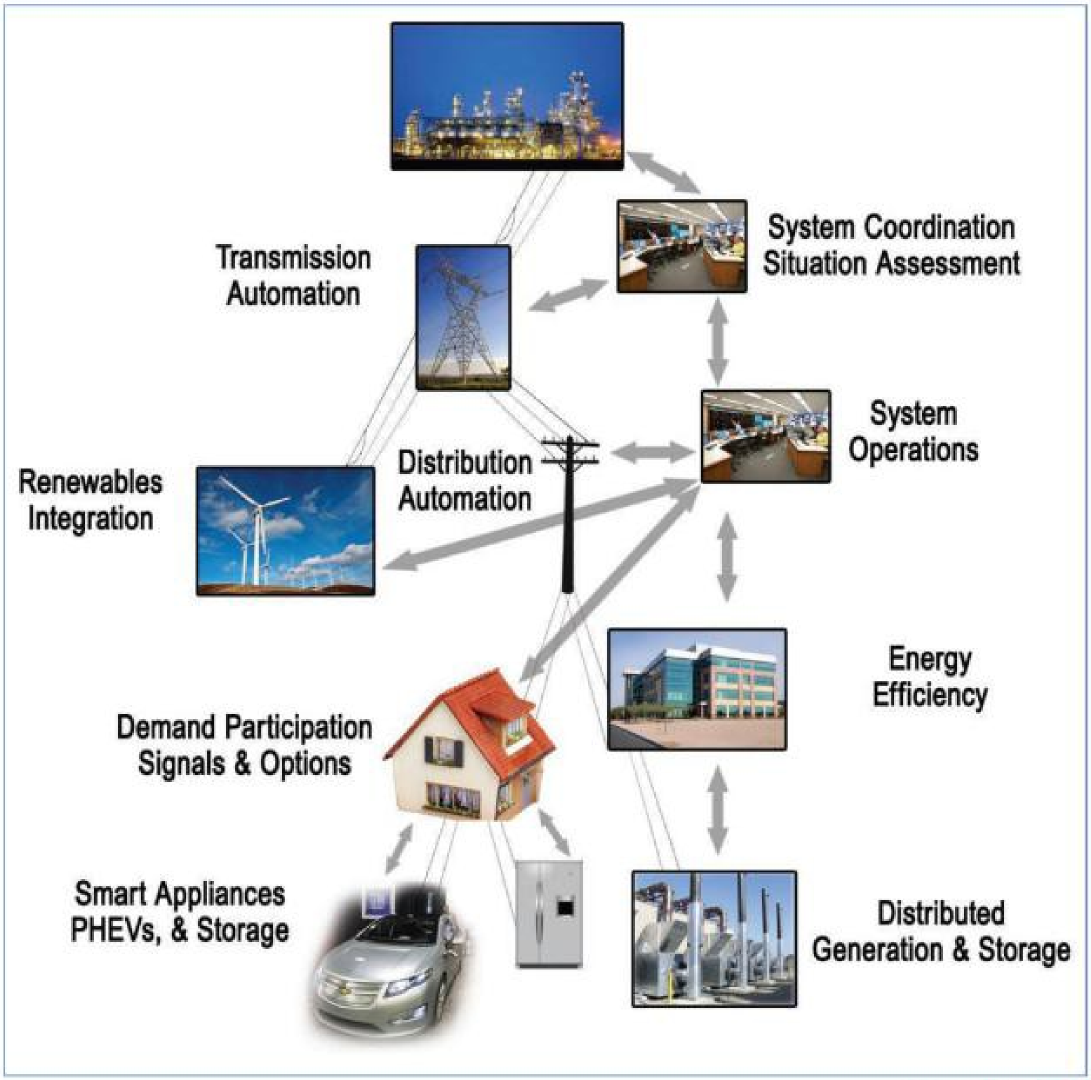
For a century, utility companies have had to send workers out to gather much of the data needed to provide electricity. The workers read meters, looked for broken equipment, and measured voltage, for example. Most of the devices to deliver electricity have yet to be automated and computerized. Now, many options and products are being made available to modernize the electricity industry.

The "grid" represents the entire network that carries electricity from the plants to consumers. The grid includes wires, substations, transformers, switches and much more. Smart grid means "computerizing" the electric utility grid. It includes adding two-way digital communication technology to devices associated with the grid. Each device on the network can be equipped with sensors to gather data (power meters, voltage sensors, fault detectors, etc.) plus two-way digital communication between the device in the field and the utility's network operation center. A key feature of the smart grid is automation technology that lets the utility adjust and control each individual device or millions of devices from a central location.

The number of applications on the smart grid is growing as fast as the innovative companies that can construct and supply the smart grid. The benefits of the smart grid include enhancing cyber-security, handling sources of electricity like wind and solar power, and even integrating electric vehicles onto the grid. The companies making the smart grid technology or offering such services include well-established communication firms, and brand new technology companies (DOE, 2011).

While EPRI defines a smart grid as the modernization of the electricity delivery system to monitor, protect, and automatically optimize the operation of its interconnected elements from the central and distributed generator through the high-voltage network and distribution system to all kinds of uses ranging from industrial users, building automation systems, electric vehicles, appliances, and other household devices(EPRI, 2009).

Fig A1 illustrates the smart gird systems from the supply to demand side which reflects the concept of safety operation, high efficiency, sustainability, reliability, economic incentives, security and environmental friendly (Provincial Authority of Thailand, 2011).



Source: US DoE

Fig A 1: Smart grid

The NDTL of DOE defines the seven key elements of smart grids as follows (National Energy Technology Laboratory of United States, 2008);

1. Active consumer participation
2. Accommodates generation and storage options
3. Enables products, services and markets
4. Provides power quality
5. Optimizes assets and operates efficiently
6. Resist attacks (response to disturbances)
7. Self-healing from operations. Resilient against attack and natural disaster

The main characteristics of smart grids are explained in Table A 1 (International Energy Agency, 2011).

Table A 1 Main characteristics of smart grids

Characteristic	Description
Enables informed participation by customers	Consumers help balance supply and demand and ensure reliability by modifying the way they use and purchase electricity. These modifications come as a result of consumers having choices that motivate different purchasing patterns and behaviors. These choices involve new technologies, new information about their electricity use, and new forms of electricity pricing and incentives.
Accommodates all generation and storage options	A smart grid accommodates not only large, centralized power plants, but also the growing array of customer-sited distributed energy resources. Integration of these resources – including renewable, small-scale combined heat and power, and energy storage – will increase rapidly all along the value chain, from suppliers to marketers to customers.
Enables new products, services and markets	Correctly designed and operated markets efficiently create an opportunity for consumers to choose among competing services. Some of the independent grid variables that must be explicitly managed are energy, capacity, location, time, rate of change and quality. Markets can play a major role in the management of these variables. Regulators, owners/operators and consumers need the flexibility to modify the rules of business to suit operating and market conditions.
Provides the power quality for the range of needs	Not all commercial enterprises, and certainly not all residential customers, need the same quality of power. A smart grid supplies varying grades (and prices) of power. The cost of premium power-quality features can be included in the electrical service contract. Advanced control methods monitor essential components, enabling rapid diagnosis and solutions to events that impact power quality, such as lightning, switching surges, line faults and harmonic sources.
Optimizes asset utilization and operating efficiency	A smart grid applies the latest technologies to optimize the use of its assets. For example, optimized capacity can be attainable with dynamic ratings, which allow assets to be used at greater loads by continuously sensing and rating their capacities. Maintenance efficiency can be optimized with condition-based maintenance, which signals the need for equipment maintenance at precisely the right time. System-control devices can be adjusted to reduce losses and eliminate congestion. Operating efficiency increases when selecting the least-cost energy-delivery system available through these types of system-control devices.
Provides resiliency to disturbances, attacks and natural disasters	Resiliency refers to the ability of a system to react to unexpected events by isolating problematic elements while the rest of the system is restored to normal operation. These self-healing actions result in reduced interruption of service to consumers and help service providers better manage the delivery infrastructure.

2. Smart grid technologies (IEA, 2011)

Smart grid technology areas govern the entire grid, from generation through transmission and distribution to various types of electricity consumers. Some of the technologies are actively being deployed and are considered mature in both their development and application, while others require further development and demonstration. A fully optimized electricity system will deploy all the technology areas in Fig A 2. However, not all technology areas need to be installed to increase the "smartness" of the grid (International Energy Agency, 2011).

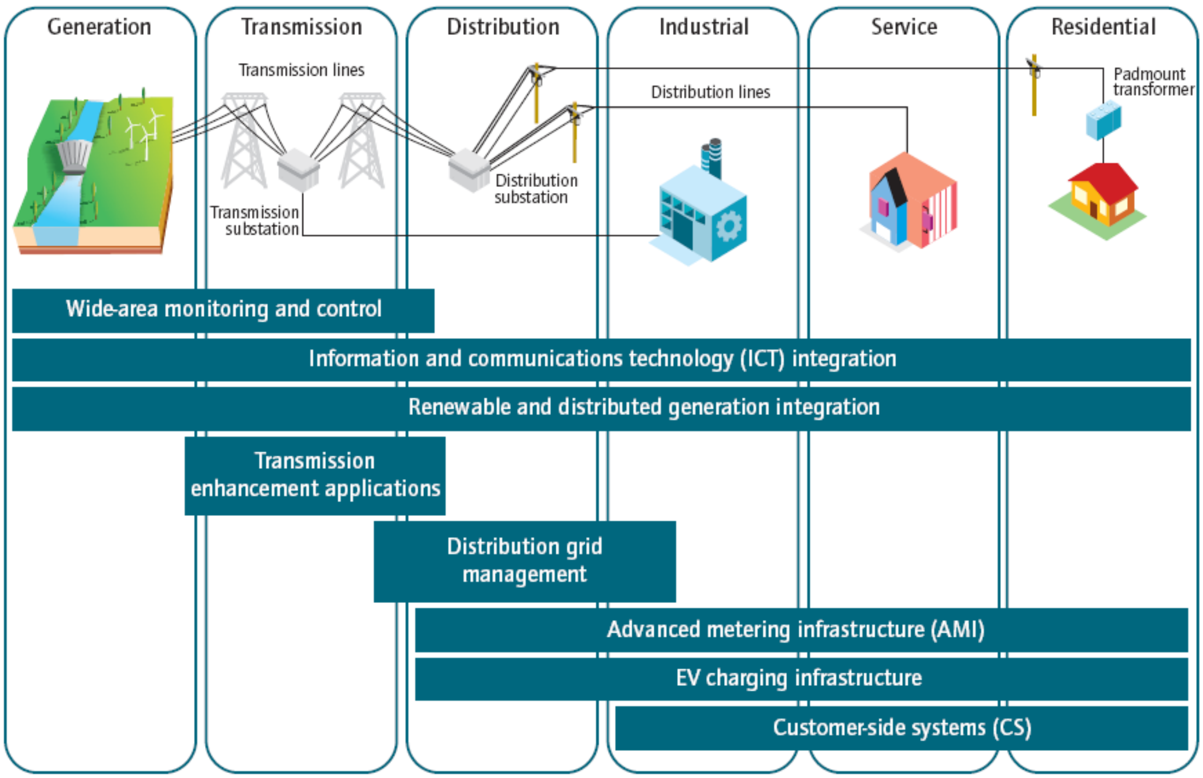


Fig A 2 Smart grid technology areas

Source: IEA (2011)(International Energy Agency, 2011)

2.1 Wide-area monitoring and control

Real-time monitoring and display of power system component and performance across interconnections and over large geographic areas help system operators to understand and optimize power system component, behavior, and performance. Advanced system operation tools avoid blackouts and facilitate the integration of variable renewable energy resources. Monitoring and control technologies along with advanced system analytics – including wide-area situational awareness (WASA), wide-area monitoring systems (WAMS), and wide-area adaptive protection, control and automation (WAAPCA) – generate data to inform decision making, mitigate wide-area disturbances, and improve transmission capacity and reliability.

2.2 Information and communication technology integration

Underlying communication infrastructure, whether using private utility communication networks (radio networks, meter mesh networks) or public carriers and networks (Internet, cellular, cable or telephone), supports data transmission for deferred and real-time operation during outages. Along with communication devices, significant computing, system control software, and enterprise resource planning software support the two-way exchange of information between stakeholders which enable more efficient use and management of the grid.

2.3 Renewable and distributed generation integration

Integration of renewable and distributed energy resources – encompassing large scale at the transmission level, medium scale at the distribution level, and small scale on commercial or residential building – can present challenges for the dispatchability and controllability of these resources and for operation of the electricity system. Energy storage systems, both electrically and thermally based, can alleviate such problems by decoupling the production and delivery of energy. Smart grids can help through automation of control of generation and demand (in addition to other forms of demand response) to ensure balancing of supply and demand.

2.4 Transmission enhancement applications

There are a number of technologies and applications for the transmission system. Flexible AC transmission systems (FACTS) are used to enhance the controllability of transmission networks and to maximize power transfer capability. The deployment of this technology on existing lines can improve efficiency and defer the need of additional investment. High voltage DC (HVDC) technologies are used to connect offshore wind and solar farms to large power areas, with decreased system losses and enhanced system controllability, allowing efficient use of energy sources remote from load centers. Dynamic line rating (DLR), which uses sensors to identify the current carrying capability of a section of network in real time, can optimize utilization of existing transmission assets, without the risk of causing overloads. High-temperature superconductors (HTS) can significantly reduce transmission losses and enable economical fault-current limiting with higher performance, though there is a debate over the market readiness of the technology.

2.5 Distribution grid management

Distribution and sub-station sensing and automation can reduce outage and repair time, maintain voltage level and improve asset management. Advanced distribution automation processes real-time information from sensors and meters for fault location, automatic reconfiguration of feeders, voltage and reactive power optimization, or to control distributed generation. Sensor technologies can enable condition- and performance-based maintenance of network components, optimizing equipment performance and hence effective utilization of assets.

2.6 Advanced metering infrastructure

Advanced metering infrastructure (AMI) involves the deployment of a number of technologies – in addition to advanced or smart meters that enable two-way flow of information, providing customers and utilities with data on electricity price and consumption, including the time and amount of electricity consumed. AMI will provide a wide range of functionalities:

- Remote consumer price signals, which can provide time-of-use pricing information.
- Ability to collect, store, and report customer energy consumption data for any required time intervals or near real time.
- Improved energy diagnostics from more detailed load profiles.

- Ability to identify location and extent of outages remotely via a metering function that sends a signal when the meter goes out and when power is restored.
- Remote connection and disconnection.
- Losses and theft detection.
- Ability for a retail energy service provider to manage its revenues through more effective cash collection and debt management.

2.7 Electric vehicle charging infrastructure

Electric vehicle charging infrastructure handles billing, scheduling, and other intelligent features for smart charging (grid-to-vehicle) during low energy demand. In the long run, it is envisioned that large charging installation will provide power system ancillary services such as capacity reserve, peak load shaving, and vehicle-to-grid regulation. This will include interaction with both AMI and customer-side systems.

2.8 Customer-side systems

Customer-side systems, which are used to help manage electricity consumption at the industrial, service and residential levels, include energy management systems, energy storage devices, smart appliances and distributed generation. Energy efficiency gains and peak demand reduction can be accelerated with in-home displays/energy dashboards, smart appliances, and local storage. Demand response includes both manual customer response and automated, price-responsive appliances and thermostats that are connected to an energy management system or controlled with a signal from the utility or system operator.

Table A2 highlights a number of hardware and systems and software associated with each technology area. Within the smart grid technology landscape, a broad range of hardware and software applications and communication technologies are at various levels of maturity.

It should be noted here that some technologies have proven themselves over time, but many have yet to be demonstrated or deployed on a large scale. Existing projects give an indication of the maturity levels and development trends of smart grid technologies which presented in Table A3.

Table A 2 Smart grid technology in both hardware and software

Technology area	Hardware	Systems and software
Wide-area monitoring and control	Phasor measurement units (PMU) and other sensor equipment	Supervisory control and data acquisition (SCADA), wide-area monitoring systems (WAMS), wide-area adaptive protection, control and automation (WAAPCA), wide area situational awareness (WASA)
Information and communication technology integration	Communication equipment (Power line carrier, WIMAX, LTE, RF mesh network, cellular), routers, relays, switches, gateway, computers (servers)	Enterprise resource planning software (ERP), customer information system (CIS)
Renewable and distributed generation integration	Power conditioning equipment for bulk power and grid support, communication and control hardware for generation and enabling storage technology	Energy management system (EMS), distribution management system (DMS), SCADA, geographic Information system (GIS)
Transmission enhancement	Superconductors, FACTS, HVDC	Network stability analysis, automatic recovery systems
Distribution grid management	Automated re-closers, switches and capacitors, remote controlled distributed generation and storage, transformer sensors, wire and cable sensors	Geographic information system (GIS), distribution management system (DMS), outage management system (OMS), workforce management system (WMS)
Advanced metering infrastructure	Smart meter, in-home displays, servers, relays	Meter data management system (MDMS)
Electric vehicle charging infrastructure	Charging infrastructure, batteries, inverters	Energy billing, smart grid-to-vehicle charging (G2V) and discharging vehicle-to-grid (V2G) methodologies
Customer-side systems	Smart appliances, routers, in-home display, building automation systems, thermal accumulators, smart thermostat	Energy dashboards, energy management systems, energy applications for smart phones and tablets.

Source: IEA (2011)(International Energy Agency, 2011)

Table A 3 Maturity levels and development trends of smart grid technologies

Technology area	Maturity level	Development trend
Wide-area monitoring and control	Developing	Fast
Information and communications technology integration	Mature	Fast
Renewable and distributed generation integration	Developing	Fast
Transmission enhancement applications	Mature	Moderate
Distribution management	Developing	Moderate
Advanced metering infrastructure	Mature	Fast
Electric vehicle charging infrastructure	Developing	Fast
Customer-side systems	Developing	Fast

Smart grids include technology areas, such as renewable energy resources and demand response, which are not exclusively associated with, but are related to smart grids. Some of these technology areas were being studied long before the term smart grid was developed and therefore may offer solutions to problems that smart grids hope to address.

Smart grids consist of four main areas including (i) power generation, (ii) transmission, (iii) distribution, and (iv) end-use. The collaboration with these electricity system technology areas has the opportunity to accelerate the useful deployment of smart grids and avoid repeating past development work. An ideal way to collaborate across these electricity system technology areas is through the IEA Implementing Agreements (IAs) 29 of the 43 IAs and 11 focus on electricity system issues as shown in Table A3, these are coordinated under the electricity co-ordination. It should be noted here that this evaluation results in Fig A3 were taken from the US point of view.

3. Main Equipment

Smart grid technologies are already used in other applications such as manufacturing and telecommunications and are being adapted for use in grid operations. In general, smart grid technology can be grouped into five key areas (DOE, 2010).

3.1 Integrated communications

Some communications are up to date, but are not uniform because they have been developed in an incremental fashion and not fully integrated. In most cases, data is being collected via a modem rather than a direct network connection. Areas for improvement include: substation automation, demand response, distribution automation, supervisory control and data acquisition (SCADA), energy management systems, wireless mesh networks and other technologies, power-line carrier communications, and fiber-optics. Integrated communications will allow for real-time control, information and data exchange to optimize system reliability, asset utilization, and security

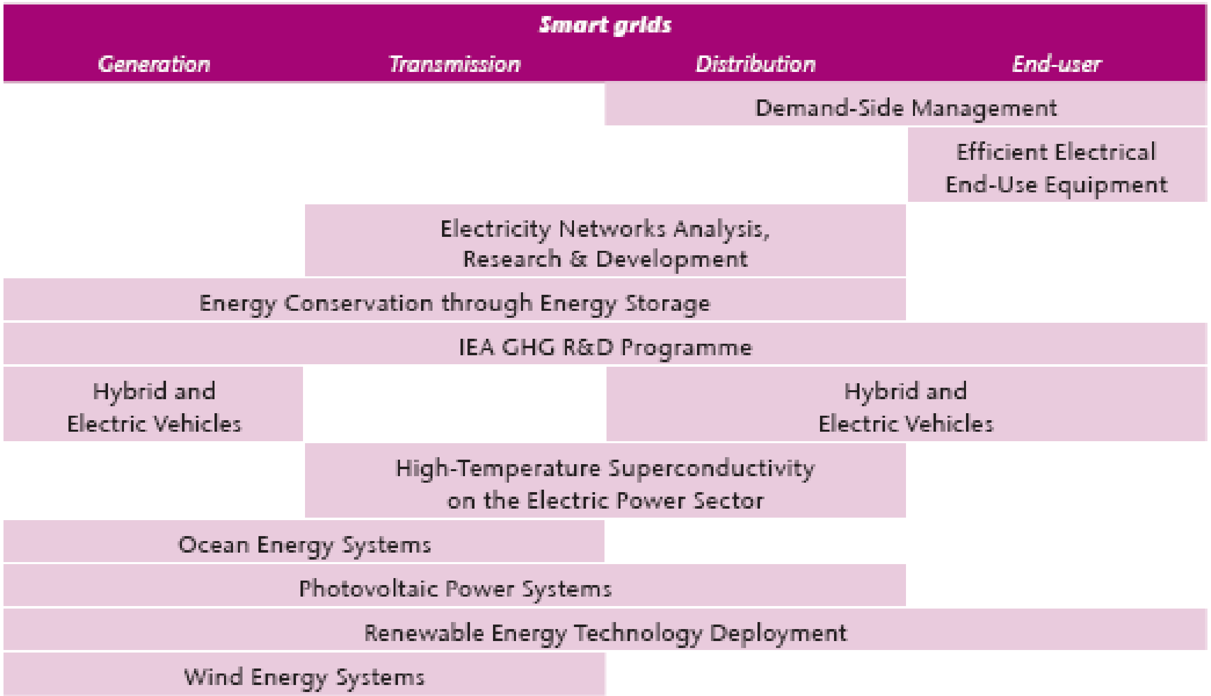


Fig A 3 Electricity sector focus for IEA ECG Implementing Agreements
Source: IEA (2011)(International Energy Agency, 2011)

3.2 Sensing and measurement

Core duties are evaluating congestion and grid stability, monitoring equipment health, energy theft prevention, and control strategies support. Technologies include: advanced microprocessor meters (smart meter) and meter reading equipment, wide-area monitoring systems, dynamic line rating (typically based on online readings by Distributed temperature sensing combined with Real time thermal rating (RTTR) systems), electromagnetic signature measurement/analysis, time-of-use and real-time pricing tools, advanced switches and cables, backscatter radio technology, and digital protective relays.

3.3 Smart meters

A smart grid replaces analog mechanical meters with digital meters that record usage in real time. Smart meters are similar to Advanced Metering Infrastructure meters and provide a communication path extending from generation plants to electrical outlets (smart socket) and other smart grid-enabled devices. By customer option, such devices can shut down during times of peak demand

3.4 Phasor measurement units

High speed sensors called PMUs distributed throughout their network can be used to monitor power quality and in some cases respond automatically to them. Phasors are representations of the waveforms of alternating current, which ideally in real-time, are identical everywhere on the network and conform to the most desirable shape. In the 1980s, it was realized that the clock pulses from global positioning system (GPS) satellites could be used for very precise time measurements in the grid. With large numbers of PMUs and the ability to compare shapes from alternating current readings everywhere on the grid, research suggests that automated systems will be able to revolutionize the management of power systems by responding to system conditions in a rapid, dynamic fashion.

A wide-area measurement system (WAMS) is a network of PMUS that can provide real- time monitoring on a regional and national scale. Many in the power systems engineering community believe that the Northeast blackout of 2003 would have been contained to a much smaller area if a wide area phasor measurement network was in place.

3.5 Advanced components

Innovations in superconductivity, fault tolerance, storage, power electronics, and diagnostics components are changing fundamental abilities and characteristics of grids. Technologies within these broad R&D categories include: flexible alternating current transmission system devices, high voltage direct current, first and second generation superconducting wire, high temperature superconducting cable, distributed energy generation and storage devices, composite conductors, and “intelligent” appliances

3.6 Advanced control

Power system automation enables rapid diagnosis of and precise solutions to specific grid disruptions or outages. These technologies rely on and contribute to each of the other four key areas. Three technology categories for advanced control methods are: distributed intelligent agents (control systems), analytical tools (software algorithms and high-speed computers), and operational applications (SCADA, substation automation, demand response, etc.). Using artificial intelligence programming techniques, Fujian power grid in China created a wide area protection system that is rapidly able to accurately calculate a control strategy and execute it. (http://en.wikipedia.org/wiki/Smart_grid - cite_note-37). The Voltage Stability Monitoring & Control (VSMC) software uses a sensitivity-based successive linear programming method to reliably determine the optimal control solution

3.7 Smart power generation

Smart power generation is a concept of matching electricity production with demand using multiple identical generators which can start, stop and operate efficiently at chosen load, independently of the others, making them suitable for base load and peaking power generation. Matching supply and demand, called load balancing, is essential for a stable and reliable supply of electricity. Short-term deviations in the balance lead to frequency variations and a prolonged mismatch results in blackouts. Operators of power transmission systems are charged with the balancing task, matching the power output of the all the generators to the load of their electrical grid. The load balancing task has become much more challenging as increasingly intermittent and variable generators such as wind turbines and solar cells are added to the grid, forcing other producers to adapt their output much more frequently than has been required in the past.

Conclusions

In conclusion, the smart energy demand mechanisms and tactics include

- smart meters,
- dynamic pricing,
- smart thermostats and smart appliances including the storage,
- automated control of equipment,
- real-time and next-day energy information feedback to electricity users, usage by appliance data
- Scheduling and controlling loads such as electric vehicle chargers, home area networks (HANs), and others.

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[i] **This fact sheet has been extracted from TNA Report – TECHNOLOGY NEEDS ASSESSMENTS REPORT FOR CLIMATE CHANGE MITIGATION – Thailand. You can access the complete report from the TNA project website http://tech-action.org/**