

Smart Grid: Trends in Power Market

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Abstract:

Since the existing power grid is designed neither by latest technologies nor to comply with rapidly climate changes, a new intelligent power grid is urgently needed and will soon be applied to power market. Smart Grid is not a technology but a combine of several latest technologies. This survey paper provides a comprehensive look at smart grid: the key technologies, main features, the perspectives and obstacles of its developments.

Keywords:

Smart Grid; Power Systems; Self-healing; Customers Participation; Sensing and Measurement; Integrated Communication; Information Management System; AMI; Renewable Sources

Table of Contents

- [1. Introduction](#)
 - [1.1 What are the issues with existing grid?](#)
 - [1.2 What is Smart Grid?](#)
 - [1.3 What are the advantages of Smart Grid?](#)
 - [2. Key Technologies](#)
 - [2.1 Sensing and Measurement](#)
 - [2.2 Information management system](#)
 - [2.3 Transmission and Distribution technology](#)
 - [3. Smart Grid Features](#)
 - [3.1 Self-healing](#)
 - [3.2 Integration among Energies and Devices](#)
 - [3.3 Consumer Participation](#)
 - [3.4 Improved Reliability](#)
 - [4. Perspectives of Smart Grid Developments](#)
 - [4.1 Smart Grid Developments in US](#)
 - [4.2 Comparison of Existing and Future Grid](#)
 - [4.3 Obstacles of Development](#)
 - [5. Summary](#)
 - [References](#)
 - [List of Acronyms](#)
-

1. Introduction

Most of the world existing electricity power systems that have been served us for a long time will soon reach their limitations. The majority of those traditional electricity power grids are neither designed in purpose to comply with rapidly climate changes and the demand for a high energy-efficiency nor use the latest technologies. That is why smart grid is not needed but will soon be put into practice.

Smart Grid which is also called intelligent grid or modern grid uses new technologies to reduce the environmental impact of power grid, energy conservation and increase efficiency, renewable energy utilization.

Section 1.1 describes the issues with the existing power grid followed by section 1.2 and 1.3 give a brief introduction of smart grid and its advantages compared to the current grid.

1.1 What are the issues with existing grid?

Electricity grid of U.S. is generated by a central power plant and distributed to different levels of customers through transmitting lines as shown in Figure 1. The voltage is stepped- up from generating stations located in the center for transmission through more than 10,000 transmission stations, stepped- down for utility distribution in over 2,000 distribution substations, may be further stepped- down at points along the utility distribution lines, and again at pad- and pole-mounted transformers to provide low-voltage service to one or a several customers [[DOE01](#)]. Even though it is providing 99.97 percent reliability, yet still has some significant issues:

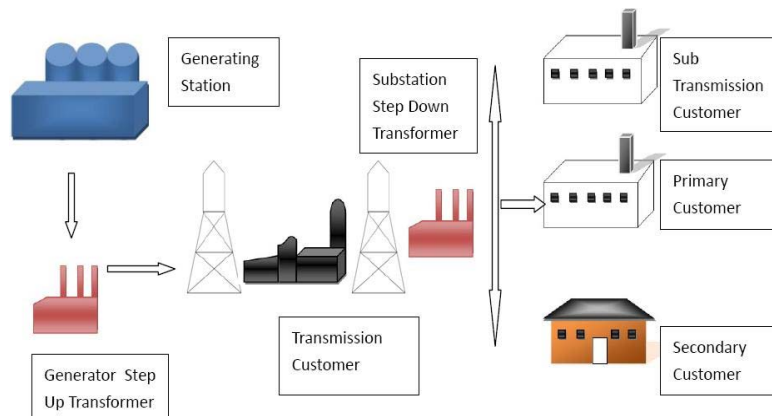


Figure 1: Existing Electricity Delivery System

(1). Limited delivery system:

The current electricity delivery uses a supervisory control and data acquisition system (SCADA) which suffers limited bandwidths and relatively slow data transmission rates that often require several seconds or more to respond to an alarm or system change and there is no visibility in the distribution network below the substation.

(2). High cost of power outage and power quality interruption:

It costs Americans \$150 billion every year for power outage and interruption. The power goes out about 2.5 hours each year which leads to high economy loss especially in industries require high quality power.

(3). Inefficiency at managing peak load:

Electricity demands vary all the time, and the cost to meet these demands changes as well. For the existing grid, supply has to change according to the demands continuously and the power grid will also need to maintain a buffer of excess supply, which results in lower efficiency, higher emissions, and higher costs.

Given the issues above, the existing grid has to change to meet the demand proposed by this modern society.

1.2 What is Smart Grid?

Smart Grid is developed by the European Technology Platform for 7th Frame Work Program. Since Smart Grid is still in research stage, there is no coincidence with the accurate definition for it, what features should it have, what goal should it achieve, what is the important point for develop it. Moreover considering the varying situations in different countries-economic development, developing strategies and policies, it is hard to obtain a unified definition [Hu].

The Energy Independence and Security Act of 2007 (EISA) directs federal and state agencies to implement programs that advance the implementation of the "Smart Grid". EISA describes "theSmart Grid" as follows:

A modernization of the Nation electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth [ISO09].

1.3 What are the advantages of Smart Grid?

Smart grid is not a single technology, but a combination of several technologies. By rational use different technologies, it can offer several potential economic and environmental benefits:

- Improved Reliability
- Higher asset utilization
- Better integration of plug-in hybrid electric vehicles (PHEVs) and renewable energy
- Reduced operating costs for utilities
- Increased efficiency and conservation
- Lower greenhouse gas (GHG) and other emissions

Figure 2 shows some key technologies and applications of Smart Grid which will be discussed in Section 2 and 3.

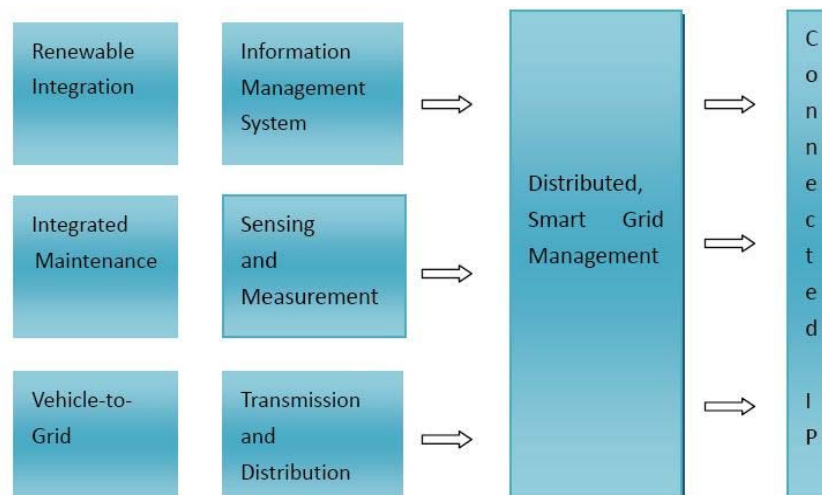


Figure 2: Key Technologies and Applications

[Back to Table of Contents](#)

2. Key Technologies

2.1 Sensing and Measurement

Sensing and measurement technology builds up a dual-communication between customers and power companies. It allows customers to acknowledge and react to the present electricity grid, meanwhile it also provide supporting data to power companies, including power quality, equipment health, power meter damage, fault location, transformer and line load, temperature of key components, power consumption and forecast data. These data will be gathered, stored and analyzed by new systems in order to be used by power companies.

Technology includes: Smart Meter, Meter Reading System and Phasor Measurement Units. Taking Figure 3 as an example to show how does it works.

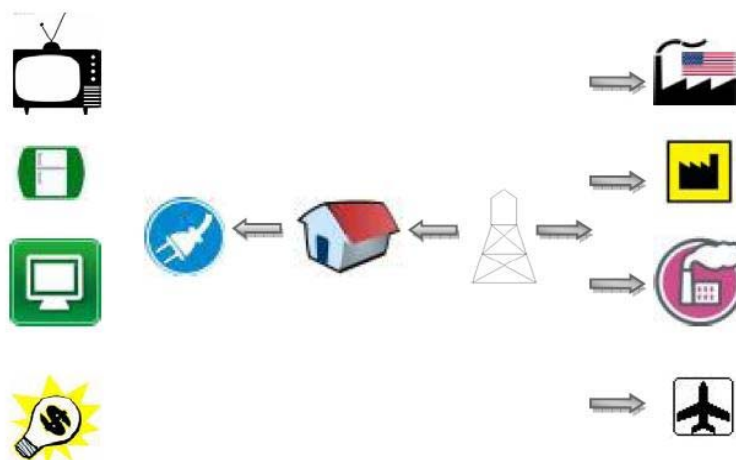


Figure 3: Smart Meter in Home Area

Smart Meter will replace the current analog mechanical meter for benefits it offers: It can store electricity price and rate from utility companies and inform the customers with best rate policy. Electricity prices vary driven by demand-and supply situation including weather conditions, demand varies over time and capacity. The existing meters only offer a flat price over a time period. With real-time information given by smart meters, households can charge cell phones, watch TV and do their laundry at peak-off time to reduce the electricity cost. It maybe a small amount for ordinary customers, but it will save billion if applied to high-tech manufacturing and critical infrastructure [Caine09]

The phasor measurement units (PMUs) measure electrical waves on an electricity grid to monitor power quality and in some case respond automatically to them. The distinction comes from its unique ability to provide synchronized phasor measurements of voltages and currents from widely dispersed locations in an electric power grid. 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 way [Liu01].

2.2 Information management system

As the development of real-time and two way communications and availability of more information, the task of information management system becomes more complicated. Information management system includes several functions: collection and processing, analysis, integration, improved interfaces, information security as shown in Figure 4.

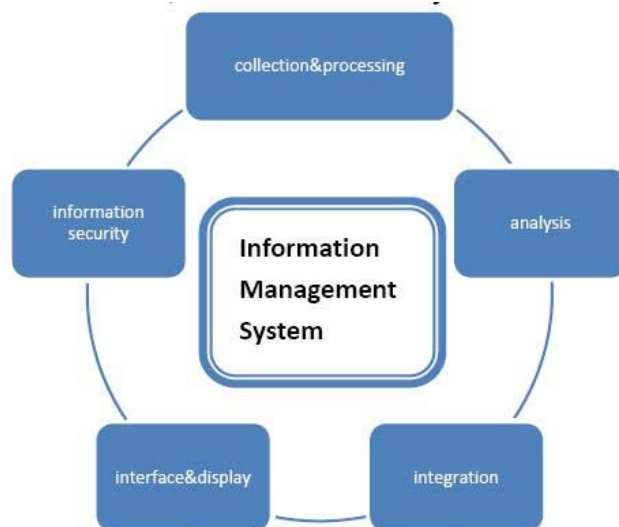


Figure 4: Information Management System

Information collection and processing include detailed real-time data collection systems, distributed data collection and processing services, and dynamic resource sharing, large-capacity high-speed access, redundant backup of intelligent electronic device(IED), etc. Information systems reduce complexity so that operators and managers have tools to effectively and efficiently operate a grid with an increasing number of variables. Technology also include visualization techniques that reduce large quantities of data into easily understood visual formats, software systems that provide multiple options when systems operator actions are required, and simulators for operational training and "what-if" analysis.

The improvement of information management system provides an option to reduce peak load efficiently and better manage the grid. For instance, Demand Response (DR) is a key application it offers. During periods of peak load, utilities companies will alter customers to reduce the operation of non-essential applications thus avoid dispatching high-cost generating units which are often among the least efficient and dirtiest.

2.3 Transmission and Distribution Technology

The Department of Energy (DOE) Electricity Advisory Committee summarized several benefits of Transmission and Distribution Technology (T&D) of smart grid. The benefits include capturing renewable production and delivering it when transmission capacity is available, relieving congestion, deferring transformer upgrades attributable to peak load growth, and providing down-circuit supply while outages are being restored.

Another possible way to improve the overburdened transmission system is to apply high-voltage direct-current (HVDC) and "flexible alternating-current transmission system" (FACTS) technology [Roger]

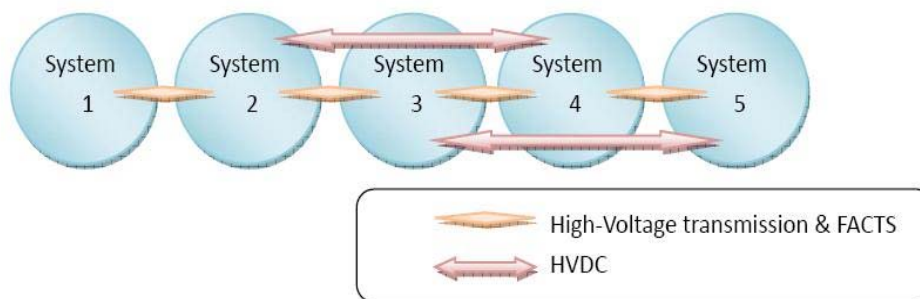


Figure 5: Large Power System Intersection

Figure 5 shows a hybrid system with HVDA and FACTS. Power exchange in neighboring areas of interconnected systems can be achieved, preferably with FACTS to increase transmission capacity and stability. The transmission of large power blocks over long distances should, however, be realized by means of HVDC links directly to the locations of power demand [CIGNE].

HVDC may be used when asynchronous systems are interconnected, power is transmitted over long distances, or the control of real power is needed [Hen01]. FACTS is a combination of solid-state switches and computerized automation that enable nearly instantaneous customized control of power flows-- far faster than traditional electromechanical switches.

HVDC and FACTS applications have the potential to provide a much-needed boost to the transmission system and some other technical advantages, especially when dynamic voltage support is needed.

[Back to Table of Contents](#)

3. Smart Grid Features

3.1 Self-healing

The security and stability calculation and development of emergency plans of current power grids are still off-line analysis, thus, the results is comparatively conservative [Lin]. However, smart grid has better self-management and self healing ability. With real-time monitoring, problems can be automatically detected and responded to. With the incorporation of micro grids affected areas can be isolated from the main networks limiting disruption.

If an overhead power line has an error, there is inevitable power loss. In the case of urban/city networks that for the most part are fed using underground cables, networks can be designed (through the use of interconnected topologies) such that failure of one part of the network will result in no loss of supply to end users.

Usually, self-healing has 3 steps:

Step1: Using AMI, the utility company collects real-time usage data.

Step 2: It analyzes the data to identify a potential power failure during a high-demand period.

Step 3: The utility redistributes power across its service area and send radio signal to turn on or off smart applications [Wordpress].

With self-healing function the power grid is able to maintain its stable operation, estimate weak stage, and deal with emergency problem.

3.2 Integrations among Energies and Devices

Considering the climate changes over decades, it is important to bring out a technology that uses renewable sources. Figure 6 shows some renewable energies. The Electric Power Research Institute (EPRI) calculates that a national smart grid could reduce annual GHG emissions by 60-211 million metric tons of carbon dioxide equivalent (MMT CO₂e) compared to business-as-usua by 2030, an amount equal to 2.5-9 percent of GHG emissions from electricity generation in 2006 [EPRI08] [EPA08].



Figure 6: Renewable Sources

Smart Grid technologies will allow the grid to better adapt to the dynamics of renewable energy and distributed generation, helping utilities and consumers more easily access these resources and reap the benefits. The existing grid was designed to move power from centralized supply sources to fixed, predictable loads; this makes it challenging for the grid to accept input from many distributed energy resources across the grid. And because resources such as solar and wind power are intermittent, the grid will require integrated monitoring and control, as well as integration with substation automation, to control differing energy flows and plan for standby capacity to supplement intermittent generation. Smart Grid capabilities will make it easier to control bi-directional power flows and monitor, control, and support these distributed resources [OE].

3.3 Consumer Participation

Consumer Participation means a power grid has the ability to accustom demand side, environment, and generators. Historically, the intelligence of the grid in North America has been demonstrated by the utilities operating it in the spirit of public service and shared responsibility, ensuring constant availability of electricity at a constant price, day in and day out, in the face of any and all hazards and changing conditions [WIKI].

A smart grid incorporates consumer equipment and behavior in grid design, operation, and communication. Customers are provided with their electrical consumption and pattern. Thus, the customers can better manage their energy use and reduce energy costs given information.

Advanced communications capabilities equip customers with tools to exploit real-time electricity pricing, incentive-based load reduction signals, or

emergency load reduction signals. In addition, smart grid can also allow the customers to save energy and sell them, for instance, by enabling distribution generation resources like residential solar panel, some small participator like individual homes and small business are allowed to sell their saved energy to neighbors or back to grid. The same will hold true for larger commercial businesses that have renewable or back-up power systems that can provide power for a price during peak demand events, typically in the summer when air condition units place a strain on the grid [WIKI].

3.4 Improved Reliability

As mentioned above, the electricity power grid is 99.97 percent reliable. It sounds good, however, in practice it costs Americans \$150 billion every year. Table 1 [DOE02] shows the cost of one hour power interruption.

Table 1. Cost of One-hour Interruption in Different Industries

Industry	Average Cost of 1-hour interruption
Cellular Communications	\$41,000
Telephone Ticket Sales	\$72,000
Airline Reservation System	\$90,000
Semiconductor Manufacturer	\$2,000,000
Credit Card Operation	\$2,580,000
Brokerage Operation	\$6,480,000

The good news is smart grid has significant improvement over power quality and reliability. The usage of smart meter mentioned in section 2.1 can efficiently inform users the working situation of meters and the price in real-time.

Two-way communications all across the grid will let utilities remotely identify, locate, isolate, and restore power outages more quickly without having to send field crews on trouble calls. In fact, a Smart Grid could eliminate up to 50% of trouble calls [Standish]. Through proactive grid management and automated response, the frequency and duration of power outages can be reduced, which will result in fewer anxious calls to utility call centers and improved consumer satisfaction. Remote monitoring and control devices throughout the system can create a self-healing grid, which can restore and prevent outages and extend the life of substation equipment and distribution assets. Through such automation, rising consumer expectations for power quality and reliability can be met in the face of growing electricity demand and an aging infrastructure and workforce [OE].

[Back to Table of Contents](#)

4. Perspectives of Smart Grid Developments

4.1 Smart Grid Developments in US

The United States focused on upgrading the power network infrastructure maximally use intelligent information technology [He].

In 2006, IBM and global power professional institute cooperated developing a solution of smart grid. Power companies can use sensors, meters, digital control equipments and analysis tools to automatically monitor network, optimize network performance, prevent power outages and restore power supply faster [Jiang].

March 2008, a small town in Colorado was built as the first U.S. smart grid city.

February 2009, IBM signed agreement with a Mediterranean island named Malta- they will build a "smart public system" together, in order to achieve country's electricity grid and water supply systems digitalization, including build a sensor network in grid [Jiang]. IBM will provide data collection and analysis software to help reduce costs and carbon emissions.

California has completed the installation of advanced metering infrastructure (AMI) to 2 million homes and the initial analysis shows that power savings can be up to 16% ~ 30% [Jiang].

Support for smart grids became federal policy with passage of the Energy Independence and Security Act of 2007. The law, Title13, sets out \$100 million in funding per fiscal year from 2008 to 2012, establishes a matching program to states, utilities and consumers to build smart grid capabilities, and creates a Grid Modernization Commission to assess the benefits of demand response and to recommend needed protocol standards. The Energy Independence and Security Act of 2007 directs the National Institute of Standards and Technology to coordinate the development of smart grid standards, which FERC would then promulgate through official rulemakings [DOE3].

Smart grids received further support with the passage of the American Recovery and Reinvestment Act of 2009, which set aside \$11 billion for the creation of a smart grid.

4.2 Comparison of Existing and Future Grid

Considering what we have discussed above, Smart Grid will be a new trend to power market that will use new technologies and bring us more benefits. Table 2 lists differences between the grid we have now and the future grid.

Table 2[DOE02]: Existing&Future Grid

Characteristic	Existing Grid	Future Grid
Enable Active Participation by Customers	Customers are uninformed and non-participate with power system	Informed, involved, and active consumers - demand response and distributed energy resources.
Accommodate All Generation and Storage Options	Dominated by central generation- many obstacles exist for distributed energy resources interconnection	Many distributed energy resources with plug-and-play convenience focus on renewables
Enable New Products, Services and Markets	Limited wholesale markets, not well integrated - limited opportunities for consumers	Mature, well-integrated wholesale markets, growth of new electricity markets for consumers
Provide Power Quality for Digital Economy	Focus on outages - slow response to power quality issues	Power quality is a priority with a variety of quality/price options - rapid resolution of issues
Optimize Assets and Operate efficiently	Little integration of operational data with asset management - business process silos	Greatly expanded data acquisition of grid parameters - focus on prevention, minimizing impact to consumers
Self-healing	Responds to prevent further damage- focus is on protecting assets following fault	Automatically detects and responds to problems - focus on prevention, minimizing impact to consumer
Operate Resiliently Against Attack and Natural Disaster	Vulnerable to malicious acts of terror and natural disasters	Resilient to attack and natural disasters with rapid restoration capabilities

4.3 Obstacles of Future Development

Security

Many of the technologies discussed above to support Smart Grid, such as smart meters, sensors, and advanced communications networks, can themselves increase the vulnerability of the grid to cyber attacks. Accordingly, it is essential that Smart Grid deployment leverage the benefits of increased threat awareness while mitigating against heightened security concerns. It will be a difficult task, but one that can be addressed by being aware of the risks and leveraging security best practices from other industries[[OE](#)].

Upfront Consumer Expenses

In the responses of 200 utility managers to a 2009 survey, 42 percent cited "upfront consumer expenses" as a major obstacle to the smart grid. These concerns were confirmed by consumer responses in which 95 percent of respondents indicated they are interested in receiving detailed information on their energy use; however, only 1 in 5 were willing to pay an upfront fee to receive that information. Regulatory approval for rate increases needed to pay for smart grid investments is always difficult, and the receptiveness of regulators varies from state to state [[OE](#)].

Lack of Standardization

Lack of technology standards has been considered as a major obstacle to smart grid deployment [[OE](#)]. A Smart Grid is a new integrated operational and conceptual model for utility operations. This requires it to both implement a system-wide installation of monitoring device and to maximally communicate with components. However, developing this kind of system will usually cost multi-years .

Because smart grid is still a new concept and the technologies that there is misunderstanding amongst consumers, regulators, policymakers, what its costs

and benefits are. Stakeholders that are generally aligned conclusions based on a different understanding of the smart grid.

[Back to Table of Contents](#)

5. Summary

A Smart Grid offers significant opportunities for utilities and consumers to wisely manage the energy consumption by the usage of advanced metering infrastructure and dual-way and real time communication. It also provides opportunities to wisely manage the fuel resources by potentially reducing the national need for additional generation sources, better integrating renewable and non-renewable generation sources into the grid operations, reducing outages and cascading problems, and enabling consumers to better manage their energy consumption. A Smart Grid can be a mechanism for achieving the worldwide goals in the areas of energy security, climate change, grid reliability, economic growth, and national competitiveness. Even it still has obstacles of development, DOE has the opportunity to address many of these challenges and accelerate the deployment schedule so that the nation can achieve the many benefits a Smart Grid offers.

[Back to Table of Contents](#)

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[Back to Table of Contents](#)

List of Acronyms

AMI	advanced metering infrastructure
DOE	Department of Energy
DR	Demand Response
EPRI	Electric Power Research Institute
EISA	Energy Independence and Security Act
FACTS	flexible alternating-current transmission system
GHG	greenhouse gas

GPS	global positioning system
HVDC	high-voltage direct-current
IED	intelligent electronic device
MAMS	Wide Area Monitoring system
MMT CO ₂ e	million metric tons of carbon dioxide equivalent
PHEV	plug-in hybrid electric vehicles
PMU	phasor measurement unit
SCADA	supervisory control and data acquisition system
SPID	Strategic Power Infrastructure Defense
T&D	Transmission and Distribution Technology

[Back to Table of Contents](#)

Last Modified: April, 2010

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