Evolution of Electric Grid-Need for smart grid- Difference between conventional & smart grid
- Overview of enabling technologies-International experience in smart grid deployment efforts-
Smart grid road map for INDIA- smart grid architecture

Evolution of the Electricity Grid

The first alternating current power grid system was installed in 1886 in Great Barrington, Massachusetts. At that time, the grid was a centralized unidirectional system of electric power transmission, electricity distribution, and demand-driven control.

In the 20th century local grids grew over time, and were eventually interconnected for economic and reliability reasons. By the 1960s, the electric grids of developed countries had become very large, mature and highly interconnected, with thousands of 'central' generation power stations delivering power to major load centres via high capacity power lines which were then branched and divided to provide power to smaller industrial and domestic users over the entire supply area. The topology of the 1960s grid was a result of the strong economies of scale: large coal-, gas- and oil-fired power stations in the 1 GW (1000 MW) to 3 GW scale are still found to be cost-effective, due to efficiency-boosting features that can be cost effective only when the stations become very large.

Power stations were located strategically to be close to fossil fuel reserves (either the mines or wells themselves, or else close to rail, road or port supply lines). Siting of hydroelectric dams in mountain areas also strongly influenced the structure of the emerging grid. Nuclear power plants were sited for availability of cooling water. Finally, fossil fuel-fired power stations were initially very polluting and were sited as far as economically possible from population centres once electricity distribution networks permitted it. By the late 1960s, the electricity grid reached the overwhelming majority of the population of developed countries, with only outlying regional areas remaining 'off-grid'.
Metering of electricity consumption was necessary on a per-user basis in order to allow appropriate billing according to the (highly variable) level of consumption of different users. Because of limited data collection and processing capability during the period of growth of the grid, fixed-tariff arrangements were commonly put in place, as well as dual-tariff arrangements where night-time power was charged at a lower rate than daytime power. The motivation for dual-tariff arrangements was the lower night-time demand. Dual tariffs made possible the use of low-cost night-time electrical power in applications such as the maintaining of 'heat banks' which served to 'smooth out' the daily demand, and reduce the number of turbines that needed to be turned off overnight, thereby improving the utilisation and profitability of the generation and transmission facilities. The metering capabilities of the 1960s grid meant technological limitations on the degree to which price signals could be propagated through the system.

Through the 1970s to the 1990s, growing demand led to increasing numbers of power stations. In some areas, supply of electricity, especially at peak times, could not keep up with this demand, resulting in poor power quality including blackouts, power cuts, and brownouts. Increasingly, electricity was depended on for industry, heating, communication, lighting, and entertainment, and consumers demanded ever higher levels of reliability.

Towards the end of the 20th century, electricity demand patterns were established: domestic heating and air-conditioning led to daily peaks in demand that were met by an array of 'peaking power generators' that would only be turned on for short periods each day. The relatively low utilisation of these peaking generators (commonly, gas turbines were used due to their relatively lower capital cost and faster start-up times), together with the necessary redundancy in the electricity grid, resulted in high costs to the electricity companies, which were passed on in the form of increased tariffs. In the 21st century, some developing countries like China, India and Brazil were seen as pioneers of smart grid deployment.

Modernization opportunities

Since the early 21st century, opportunities to take advantage of improvements in electronic communication technology to resolve the limitations and costs of the electrical grid have become apparent. Technological limitations on metering no longer force peak power prices
to be averaged out and passed on to all consumers equally. In parallel, growing concerns over environmental damage from fossil-fired power stations has led to a desire to use large amounts of renewable energy. Dominant forms such as wind power and solar power are highly variable, and so the need for more sophisticated control systems became apparent, to facilitate the connection of sources to the otherwise highly controllable grid. Power from photovoltaic cells (and to a lesser extent wind turbines) has also, significantly, called into question the imperative for large, centralised power stations. The rapidly falling costs point to a major change from the centralised grid topology to one that is highly distributed, with power being both generated and consumed right at the limits of the grid. Finally, growing concern over terrorist attack in some countries has led to calls for a more robust energy grid that is less dependent on centralised power stations that were perceived to be potential attack targets.

Evolution of "Smart Grid"

The first official definition of Smart Grid was provided by the Energy Independence and Security Act of 2007 (EISA-2007), which was approved by the US Congress in January 2007, and signed to law by President George W. Bush in December 2007. Title XIII of this bill provides a description, with ten characteristics, that can be considered a definition for Smart Grid, as follows:

"It is the policy of the United States to support the modernization of the Nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth”

To achieve each of the following, which together characterize a Smart Grid:

(1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.

(2) Dynamic optimization of grid operations and resources, with full cyber-security.

(3) Deployment and integration of distributed resources and generation, including renewable resources.

(4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources.
(5) Deployment of `smart' technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.

(6) Integration of `smart' appliances and consumer devices.

(7) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal storage air conditioning.

(8) Provision to consumers of timely information and control options.

(9) Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.

(10) Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services."

A common element to most definitions is the application of digital processing and communications to the power grid, making data flow and information management central to the smart grid. Various capabilities result from the deeply integrated use of digital technology with power grids. Integration of the new grid information is one of the key issues in the design of smart grids. Electric utilities now find themselves making three classes of transformations: improvement of infrastructure, called the *strong grid* in China; addition of the digital layer, which is the essence of the *smart grid*; and business process transformation, necessary to capitalize on the investments in smart technology. Much of the work that has been going on in electric grid modernization, especially substation and distribution automation, is now included in the general concept of the smart grid.
Early technological innovations

Smart grid technologies emerged from earlier attempts at using electronic control, metering, and monitoring. In the 1980s, automatic meter reading was used for monitoring loads from large customers, and evolved into the Advanced Metering Infrastructure of the 1990s, whose meters could store how electricity was used at different times of the day. Smart meters add continuous communications so that monitoring can be done in real time, and can be used as a gateway to demand response-aware devices and "smart sockets" in the home. Early forms of such demand side management technologies were dynamic demand aware devices that passively sensed the load on the grid by monitoring changes in the power supply frequency. Devices such as industrial and domestic air conditioners, refrigerators and heaters adjusted their duty cycle to avoid activation during times the grid was suffering a peak condition. Beginning in 2000, Italy's Telegestore Project was the first to network large numbers (27 million) of homes using smart meters connected via low bandwidth power line communication. Some experiments used the term broadband over power lines (BPL), while others used wireless technologies such as mesh networking promoted for more reliable connections to disparate devices in the home as well as supporting metering of other utilities such as gas and water.

Monitoring and synchronization of wide area networks were revolutionized in the early 1990s when the Bonneville Power Administration expanded its smart grid research with prototype sensors that are capable of very rapid analysis of anomalies in electricity quality over very large geographic areas. The culmination of this work was the first operational Wide Area...
Measurement System (WAMS) in 2000. Other countries are rapidly integrating this technology. China started having a comprehensive national WAMS system when the past 5-year economic plan completed in 2012.

FEATURES OF THE SMART GRID

The smart grid represents the full suite of current and proposed responses to the challenges of electricity supply. Because of the diverse range of factors there are numerous competing taxonomies and no agreement on a universal definition. Nevertheless, one possible categorization is given here.

Reliability

The smart grid will make use of technologies, such as state estimation, that improve fault detection and allow self-healing of the network without the intervention of technicians. This will ensure more reliable supply of electricity, and reduced vulnerability to natural disasters or attack. The economic impact of improved grid reliability and resilience is the subject of a number of studies and can be calculated using a US DOE funded methodology for US locations using at least one calculation tool.

Flexibility in network topology

Next-generation transmission and distribution infrastructure will be better able to handle possible bidirectional energy flows, allowing for distributed generation such as from photovoltaic panels on building roofs, but also the use of fuel cells, charging to/from the batteries of electric cars, wind turbines, pumped hydroelectric power, and other sources.

Efficiency

Numerous contributions to overall improvement of the efficiency of energy infrastructure are anticipated from the deployment of smart grid technology, in particular including demand-side management. The overall effect is less redundancy in transmission and distribution lines, and greater utilization of generators, leading to lower power prices.
Load adjustment/Load balancing

The total load connected to the power grid can vary significantly over time. Although the total load is the sum of many individual choices of the clients, the overall load is not a stable, slow varying, increment of the load if a popular television program starts and millions of televisions will draw current instantly. Traditionally, to respond to a rapid increase in power consumption, faster than the start-up time of a large generator, some spare generators are put on a dissipative standby mode. A smart grid may warn all individual television sets, or another larger customer, to reduce the load temporarily (to allow time to start up a larger generator) or continuously (in the case of limited resources).

Peak curtailment/leveling and time of use pricing

To reduce demand during the high cost peak usage periods, communications and metering technologies inform smart devices in the home and business when energy demand is high and track how much electricity is used and when it is used. It also gives utility companies the ability to reduce consumption by communicating to devices directly in order to prevent system overloads. Examples would be a utility reducing the usage of a group of electric vehicle charging stations or shifting temperature set points of air conditioners in a city. To motivate them to cut back use and perform what is called peak curtailment or peak leveling, prices of electricity are increased during high demand periods, and decreased during low demand periods.

Sustainability

The improved flexibility of the smart grid permits greater penetration of highly variable renewable energy sources such as solar power and wind power, even without the addition of energy storage. Current network infrastructure is not built to allow for many distributed feed-in points, and typically even if some feed-in is allowed at the local (distribution) level, the transmission-level infrastructure cannot accommodate it. Rapid fluctuations in distributed generation, such as due to cloudy or gusty weather, present significant challenges to power engineers who need to ensure stable power levels through varying the output of the more controllable generators such as gas turbines and hydroelectric generators. Smart grid technology
is a necessary condition for very large amounts of renewable electricity on the grid for this reason.

Market-enabling

The smart grid allows for systematic communication between suppliers (their energy price) and consumers (their willingness-to-pay), and permits both the suppliers and the consumers to be more flexible and sophisticated in their operational strategies. Only the critical loads will need to pay the peak energy prices, and consumers will be able to be more strategic in when they use energy.

Demand response support

Demand response support allows generators and loads to interact in an automated fashion in real time, coordinating demand to flatten spikes. Eliminating the fraction of demand that occurs in these spikes eliminates the cost of adding reserve generators, cuts wear and tear and extends the life of equipment, and allows users to cut their energy bills by telling low priority devices to use energy only when it is cheapest. Demand response can be provided by commercial, residential loads, and industrial loads.

Latency of the data flow is a major concern, with some early smart meter architectures allowing actually as long as 24 hours delay in receiving the data, preventing any possible reaction by either supplying or demanding devices.

Platform for advanced services

As with other industries, use of robust two-way communications, advanced sensors, and distributed computing technology will improve the efficiency, reliability and safety of power delivery and use. It also opens up the potential for entirely new services or improvements on existing ones, such as fire monitoring and alarms that can shut off power, make phone calls to emergency services, etc.
NEED FOR SMART GRID

With a population of over a billion people and a current GDP growth rate of about 8 percent, India is certainly one of the fastest growing countries in the world. Despite its robust economic growth, the country is still plagued by basic problems such as shortage of electricity, with nearly 40 percent of its rural households having no access to electricity.

Although India has almost doubled its energy generation in the past decade by adding over 85 GW of capacity, its grid systems lose more than 30 GW of this generated power. This is highly disturbing to people working in the power sector in India, who are concerned with the efficiency of the distribution of electricity.

The World Resources Institute estimates electricity transmission and distribution losses in India to be 27 percent - the highest in the world. This is a huge wastage of one of the most environmentally unfriendly commodities to produce.

These insights lead Technavio to believe that India needs the help of new technology to ensure better monitoring and control of electricity transmission and distribution.

A Smart Grid is a digital electrical grid that facilitates the gathering and distribution of information with regard to the usage of power by suppliers and consumers. This will lead to electricity services becoming more reliable, efficient, cost-effective, and environmentally conscious.

Advantages of Smart Grid Technology

- Help businesses reduce their carbon footprint
- New opportunities for tech companies
- Reduce cost of power cuts
- Meet increasing demand for power supply in India

Why implement the Smart Grid now?

Since about 2005, there has been increasing interest in the Smart Grid. The recognition that ICT offers significant opportunities to modernise the operation of the electrical networks has
coincided with an understanding that the power sector can only be de-carbonized at a realistic cost if it is monitored and controlled effectively. In addition, a number of more detailed reasons have now coincided to stimulate interest in the Smart Grid.

1. **Ageing assets and lack of circuit capacity**

   In many parts of the world (for example, the USA and most countries in Europe), the power system expanded rapidly from the 1950s and the transmission and distribution equipment that was installed then is now beyond its design life and in need of replacement. The capital costs of like-for-like replacement will be very high and it is even questionable if the required power equipment manufacturing capacity and the skilled staff are now available. The need to refurbish the transmission and distribution circuits is an obvious opportunity to innovate with new designs and operating practices.

   In many countries the overhead line circuits, needed to meet load growth or to connect renewable generation, have been delayed for up to 10 years due to difficulties in obtaining rights-of-way and environmental permits. Therefore some of the existing power transmission and distribution lines are operating near their capacity and some renewable generation cannot be connected. This calls for more intelligent methods of increasing the power transfer capacity of circuits dynamically and rerouting the power flows through less loaded circuits.

2. **Thermal constraints**

   Thermal constraints in existing transmission and distribution lines and equipment are the ultimate limit of their power transfer capability. When power equipment carries current in excess of its thermal rating, it becomes over-heated and its insulation deteriorates rapidly. This leads to a reduction in the life of the equipment and an increasing incidence of faults. If an overhead line passes too much current, the conductor lengthens, the sag of the catenary increases, and the clearance to the ground is reduced. Any reduction in the clearance of an overhead line to the ground has important consequences both for an increase in the number of faults but also as a danger to public safety. Thermal constraints depend on environmental conditions, that change through the year. Hence the use of dynamic ratings can increase circuit capacity at times.
3. Operational constraints

Any power system operates within prescribed voltage and frequency limits. If the voltage exceeds its upper limit, the insulation of components of the power system and consumer equipment may be damaged, leading to short-circuit faults. Too low a voltage may cause malfunctions of customer equipment and lead to excess current and tripping of some lines and generators. The capacity of many traditional distribution circuits is limited by the variations in voltage that occur between times of maximum and minimum load and so the circuits are not loaded near to their thermal limits. Although reduced loading of the circuits leads to low losses, it requires greater capital investment.

Renewable energy generation (for example, wind power, solar PV power) has a varying output which cannot be predicted with certainty hours ahead. A large central fossil-fuelled generator may require 6 hours to start up from cold. Some generators on the system (for example, a large nuclear plant) may operate at a constant output for either technical or commercial reasons. Thus maintaining the supply-demand balance and the system frequency within limits becomes difficult. Part-loaded generation ‘spinning reserve’ or energy storage can address this problem but with a consequent increase in cost. Therefore, power system operators increasingly are seeking frequency response and reserve services from the load demand. It is thought that in future the electrification of domestic heating loads (to reduce emissions of CO$_2$) and electric vehicle charging will lead to a greater capacity of flexible loads. This would help maintain network stability, reduce the requirement for reserve power from part-loaded generators and the need for network reinforcement.

4. Security of supply

Modern society requires an increasingly reliable electricity supply as more and more critical loads are connected. The traditional approach to improving reliability was to install additional redundant circuits, at considerable capital cost and environmental impact. Other than disconnecting the faulty circuit, no action was required to maintain supply after a fault. A Smart Grid approach is to use intelligent post-fault reconfiguration so that after the (inevitable) faults in the power system, the supplies to customers are maintained but to avoid the expense of multiple circuits that may be only partly loaded for much of their lives. Fewer redundant circuits result
in better utilization of assets but higher electrical losses.

5. National initiatives

Many national governments are encouraging Smart Grid initiatives as a cost-effective way to modernise their power system infrastructure while enabling the integration of low-carbon energy resources. Development of the Smart Grid is also seen in many countries as an important Economic/commercial opportunity to develop new products and services.

A lot has been done to mitigate the potential for blackouts—particularly in the effort to provide new technologies that can help make electricity more reliable, in order to sustain an increasingly high-tech economy which is based, in part, on the use of power-sensitive equipment. Many of these technologies are ready for wide deployment now, while others are only now entering demonstrations.

CONVENTIONAL GRID (TODAY ’S GRID) VERSUS THE SMART GRID

As mentioned, several factors contribute to the inability of today ’s grid to efficiently meet the demand for reliable power supply. Table compares the characteristics of today ’s grid with the preferred characteristics of the smart grid.

<table>
<thead>
<tr>
<th>SL.No</th>
<th>Preferred Characteristics</th>
<th>Conventional Grid (or) Today ’s Grid</th>
<th>Smart Grid</th>
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<tbody>
<tr>
<td>1</td>
<td>Active Consumer Participation</td>
<td>Consumers are uninformed and do not participate</td>
<td>Informed, involved consumers — demand response and distributed energy resources</td>
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<td>2</td>
<td>Accommodation of all generation and storage options</td>
<td>Dominated by central generation — many obstacles exist for distributed energy resources interconnection</td>
<td>Many distributed energy resources with plug-and-play convenience focus on renewables</td>
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<td>3</td>
<td>New products, services, and markets</td>
<td>Limited, poorly integrated wholesale markets; limited opportunities for consumers</td>
<td>Mature, well-integrated wholesale markets; growth of new electricity markets for consumers</td>
</tr>
<tr>
<td>4</td>
<td>Provision of power quality for the digital economy</td>
<td>Focus on outages — slow response to power quality issues</td>
<td>Power quality a priority with a variety of quality/price options — rapid resolution of issues</td>
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<tr>
<td>5</td>
<td>Optimization of assets and operates efficiently</td>
<td>Little integration of operational data with asset management—business process silos</td>
<td>Greatly expanded data acquisition of grid parameters; focus on prevention, minimizing impact to consumers</td>
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<td>6</td>
<td>Anticipating responses to system disturbances (self-healing)</td>
<td>Responds to prevent further damage; focus on protecting assets following a fault</td>
<td>Automatically detects and responds to problems; focus on prevention, minimizing impact to consumers</td>
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<tr>
<td>7</td>
<td>Resiliency against cyber attack and natural disasters</td>
<td>Vulnerable to malicious acts of terror and natural disasters; slow response</td>
<td>Resilient to cyber attack and natural disasters; rapid restoration capabilities</td>
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OVERVIEW OF ENABLING TECHNOLOGIES

Overview of the technologies required for the Smart Grid

To fulfill the different requirements of the Smart Grid, the following enabling technologies must be developed and implemented:

1. *Information and communications technologies*:

   These include:

   (a) Two-way communication technologies to provide connectivity between different components in the power system and loads;

   (b) Open architectures for plug-and-play of home appliances; electric vehicles and micro generation;

   (c) Communications, and the necessary software and hardware to provide customers with greater information, enable customers to trade in energy markets and enable customers to provide demand-side response;

   (d) Software to ensure and maintain the security of information and standards to provide scalability and interoperability of information and communication systems.

2. *Sensing, measurement, control and automation technologies*:

   These include:

   (a) Intelligent Electronic Devices (IED) to provide advanced protective relaying, measurements, fault records and event records for the power system;

   (b) Phasor Measurement Units (PMU) and Wide Area Monitoring, Protection and Control (WAMPAC) to ensure the security of the power system;
(c) Integrated sensors, measurements, control and automation systems and information and communication technologies to provide rapid diagnosis and timely response to any event in different parts of the power system.

(d) Smart appliances, communication, controls and monitors to maximise safety, comfort, convenience, and energy savings of homes;

(e) Smart meters, communication, displays and associated software to allow customers to have greater choice and control over electricity and gas use.

3. Power electronics and energy storage:

These include:

(a) High Voltage DC (HVDC) transmission and back-to-back schemes and Flexible AC Transmission Systems (FACTS) to enable long distance transport and integration of renewable energy sources;

(b) different power electronic interfaces and power electronic supporting devices to provide efficient connection of renewable energy sources and energy storage devices;

(c) series capacitors, Unified Power Flow Controllers (UPFC) and other FACTS devices to provide greater control over power flows in the AC grid;

(d) HVDC, FACTS and active filters together with integrated communication and control to ensure greater system flexibility, supply reliability and power quality;

(e) Power electronic interfaces and integrated communication and control to support system operations by controlling renewable energy sources, energy storage and consumer loads;

(f) Energy storage to facilitate greater flexibility and reliability of the power system.

(i) Wide Area Monitoring Systems (WAMS)

WAMS are designed by the utilities for optimal capacity of the transmission grid and to prevent the spread of disturbances. By providing real-time information on stability and operating safety margins, WAMS give early warnings of system disturbances for the prevention and mitigation of system-wide blackouts. WAMS utilize sensors distributed throughout the network in conjunction with GPS satellites for precise time stamping of measurements in the transmission system. The integrated sensors will interface with the communication network. Phasor Measurements are a current technology that is a component of most smart grid designs.
(ii) Phasor Measurement Units (PMU)

Phasor Measurement Units or Synchrophasors give operators a time-stamped snapshot of the power system. The PMUs consist of bus voltage phasors and branch current phasors, in addition to information such as locations and other network parameters. Phasor measurements are taken with high precision from different points of the power system at the same instant, allowing an operator to visualize the exact angular difference between different locations. PMUs are equipped with GPS receivers which allow synchronization of readings taken at distant points. Microprocessor-based instrumentation such as protection relays and Disturbance Fault Recorders (DFRs) incorporate the PMU module with other existing functionalities as an extended feature. The IEEE standard on Synchrophasors specifies the protocol for communicating the PMU data to the Phasor Data Concentrator. Figure illustrates the PMU measurement System.

PMUs ensure voltage and current with high accuracy at a rate of 2.88 kHz. They can calculate real power, reactive power, frequency, and phase angle 12 times per 60 hertz cycle. The actual sampling rate used to achieve this output is 1.4 MHz. Recent trends now require fast controls and online implementations for mitigating voltage collapse in the shortest, least-cost time.

(iii) Smart Meters

Smart meters have two functions: providing data on energy usage to customers (end-users) to help control cost and consumption; sending data to the utility for load factor control, peak-load requirements, and the development of pricing strategies based on consumption information and so on. Automated data reading is an additional component of both smart meters and two-way communication between customers and utilities. The development of smart meters is planned for electricity, water, and gas consumption.

Smart meters equip utility customers with knowledge about how much they pay per kilowatt hour and how and when they use energy. This will result in better pricing information and more accurate bills in addition to ensuring faster outage detection and restoration by the utility. Additional features will allow for demand-response rates, tax credits, tariff options, and participation in voluntary rewards programs for reduced consumption. Still, other features will include remote connect/disconnect of users, appliance control and monitoring, smart thermostat, enhanced grid monitoring, switching, and prepaid metering.
(iv) Smart Appliances

Smart appliances cycle up and down in response to signals sent by the utility. The appliances enable customers to participate in voluntary demand response programs which award credits for limiting power use in peak demand periods or when the grid is under stress. An override function allows customers to control their appliances using the Internet.

Air conditioners, space heaters, water heaters, refrigerators, washers, and dryers represent about 20% of total electric demand during most of the day and throughout the year. Grid-friendly appliances use a simple computer chip that can sense disturbances in the grid’s power frequency and can turn an appliance off for a few minutes to allow the grid to stabilize during a crisis.

(v) Advanced Metering Infrastructure (AMI)

AMI is the convergence of the grid, the communication infrastructure, and the supporting information infrastructure. The network-centric AMI coupled with the lack of a composite set of cross industry AMI security requirements and implementation guidance, is the primary motivation for its development. The problem domains to be addressed within AMI implementations are relatively new to the utility industry; however, precedence exists for implementing large-scale, network-centric solutions with high information assurance requirements. The defense, cable, and telecom industries offer many examples of requirements, standards, and best practices that are directly applicable to AMI implementations.

INTERNATIONAL EXPERIENCE IN SMART GRID DEPLOYMENT EFFORTS

INTERNATIONAL INITIATIVES

Many national governments are encouraging Smart Grid initiatives as a cost-effective way to modernise their power system infrastructure while enabling the integration of low-carbon energy resources. Development of the Smart Grid is also seen in many countries as an important Economic/commercial opportunity to develop new products and services. The major initiatives being in US, UK, Ireland, Italy, France, Germany, Spain, South Korea, Japan, Australia, Brazil and China. A summary of the major Smart Grid Initiatives worldwide is given ahead. Considering the benefits of Smart Grid implementation, it is also being implemented in India.
1. China

The Chinese government has declared that by 2020 the carbon emission per-unit of GDP will reduce to 40~45 per cent of that in 2008. Other drivers for developing the Smart Grid in China are the nation’s rapid economic growth and the uneven geographical distribution of electricity generation and consumption.

The State Grid Corporation of China (SGCC) has released a medium-long term plan of the development of the Smart Grid. The SGCC interprets the Smart Grid as

“A strong and robust electric power system, which is backboned with Ultra High Voltage (UHV) networks; based on the coordinated development of power grids at different voltage levels; supported by information and communication infrastructure; characterized as an automated, and interoperable power system and the integration of electricity, information, and business flows.”

2. The European Union

The SmartGrids Technology Platform of the European Union (EU) has published a vision and strategy for Europe’s electricity networks of the future. It states:

“It is vital that Europe’s electricity networks are able to integrate all low carbon generation technologies as well as to encourage the demand side to play an active part in the supply chain. This must be done by upgrading and evolving the networks efficiently and economically.”

The Smart Grids Technology Platform identified the following important areas as key challenges that impact on the delivery of the EU-mandated targets for the utilisation of renewable energy, efficiency and carbon reductions by 2020 and 2050:

- Strengthening the grid, including extending it offshore;
- Developing decentralized architectures for system control;
- Delivering communications infrastructure;
- Enabling an active demand side;
- Integrating intermittent generation;
- Enhancing the intelligence of generation, demand and the grid;
Capturing the benefits of distributed generation (DG) and storage; Preparing for electric vehicles.

3. Japan

In 2009, the Japanese government declared that by 2020 carbon emissions from all sectors will be reduced to 75 per cent of those in 1990 or two-thirds of those in 2005. In order to achieve this target, 28 GW and 53 GW of photovoltaic (PV) generations are required to be installed in the power grid by 2020 and 2030. The mandate given to these committees was to discuss the following technical and regulatory issues regarding the large penetration of renewable energy, especially PV generation, into the power grid:

- Surplus power under light load conditions;
- Frequency fluctuations;
- Voltage rise on distribution lines;
- Priority interconnection, access and dispatching for renewable energy-based generators;
- Cost recovery for building the Smart Grid.

Since the Tohoku earthquake on 11 March 2011, the Smart Grid has been attracting much attention for the reconstruction of the damaged districts and the development of a low-carbon society.

4. The UK

The Department of Energy and Climate Change document *Smarter Grids: The Opportunity* states that the aim of developing the Smart Grid is to provide flexibility to the current electricity network, thus enabling a cost-effective and secure transition to a low-carbon energy system. The Smart Grid route map recognises a number of critical developments that will drive the UK electrical system towards a low carbon system. These include:

- Rapid expansion of intermittent renewables and less flexible nuclear generation in conjunction with the retirement of flexible coal generation;
- Electrification of heating and transport;
- Penetration of distributed energy resources which include distributed generation, demand response and storage;
- Increasing penetration of electric vehicles.
5. The USA

According to Public Law 110-140-DEC. 19, 2007, the United States of America (the USA)

"Is supporting modernization of the electricity transmission and distribution networks to maintain a reliable and secure electricity infrastructure that can meet future demand growth and to achieve increased use of digital information and controls technology; dynamic optimization of grid operations and resources; deployment and integration of distributed resources and generation; development and incorporation of demand response, demand-side resources, and energy-efficient resources; development of 'smart' technologies for metering, communications and status, and distribution automation; integration of 'smart' appliances and consumer devices; deployment and integration of advanced electricity storage and peak-shaving technologies; provisions to consumers of timely information and control options and development of standards for communication and inter-operability."

6. Spain

In 2008, the government mandated distribution companies to replace existing meters with new smart meters; this must be done at no additional cost to the customer. The utility Endesa aims to deploy automated meter management to more than 13 million customers on the low voltage network from 2010 to 2015, building on past efforts by the Italian utility ENEL. The communication protocol used will be open. The utility Iberdrola will replace 10 million meters.

7. Germany

The E-Energy funding programme has several projects focusing on ICTs for the energy system.

8.2.8. Australia The Australian government announced the AUD 100 million “Smart Grid, Smart City” initiative in 2009 to deliver a commercial-scale smart grid demonstration project. Additional efforts in the area of renewable energy deployments are resulting in further study on smart grids.
9. United Kingdom

The energy regulator OFGEM has an initiative called the Registered Power Zone that will encourage distributors to develop and implement innovative solutions to connect distributed generators to the network. OFGEM has set up a Low Carbon Networks fund that will allow up to GPB 500m support to DSO projects that test new technology, operating and commercial arrangements.

10. France

The electricity distribution operator ERDF is deploying 300,000 smart meters in a pilot project based on an advanced communication protocol named Linky. If the pilot is deemed a success, ERDF will replace all of its 35 million meters with Linky smart meters from 2012 to 2016.

11. India

India has already established the India Smart Grid Task Force & India Smart Grid Forum to develop the framework and national policy. In this regard roadmap for future activities has already been released. Govt. of India has approved 14 pilot projects across the country for demonstration of different functionalities. Govt. of India has projected an outlay of about Rs. 9500 Cr. for Smart Grid development during 12th plan period (2012-17).

POWERGRID has taken a leading initiative in developing Puducherry as pilot smart grid project through collaborative efforts. Around 57 organizations has joined their hands for the project, where different attributes of Smart grid are being implemented in a holistic manner.

ON-GOING SMART GRID ACTIVITIES

APDRP, R-APDRP initiative for distribution reform (AT&C focus)
DRUM India - Distribution Reform Upgrade, Management
Four Pilot Project Sites (North Delhi, Bangalore, Gujarat, Maharashtra)
KEPCO project in Kerala India - $10 Billion initiative for Smart-Grid
L&T and Telvent project - Maharashtra - Distribution Management System roll-out
“Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders”

In order to achieve this vision, stakeholders are advised to formulate state/utility specific policies and programs in alignment with following broad policies and targets which are in line with MoP's overarching policy objective of Access, Availability and Affordability of Power for All:

A) Distribution (Including Distributed Generation)

1. Appropriate policies and programs to provide access to electricity for all with uninterrupted life line supply (8 hours/day minimum, including the evening peak) and electrification of 100% households by 2017 and continuous improvement in quality and quantum of supply.

2. Enabling programs and projects in distribution utilities to reduce AT&C losses to below 15% by 2017, below 12% by 2022, and below 10% by 2027.

3. Integrated technology trials through a set of smart grid pilot projects by 2015; and based on outcome of the pilots, full rollout of smart grids in pilot project areas by 2017; in major urban areas by 2022 and nationwide by 2027.

4. Modernization of distribution sub-stations and conversion of sub-stations in all urban areas (starting with metro cities) to Gas Insulated Substations based on techno-commercial feasibility in a phased manner through innovative financing models.

5. Development of Microgrids, storage options, virtual power plants (VPP), solar photovoltaic to grid (PV2G), and building to grid (B2G) technologies in order to manage peak demand, optimally use installed capacity and eliminate load shedding and black-outs.

6. Policies for mandatory roof top solar power generation for large establishments, i.e., with connected load more than 20kW or otherwise defined threshold.

7. Microgrids in 1000 villages/industrial parks/commercial hubs by 2017 and10,000 villages/industrial parks/commercial hubs by 2022, which can island from the main grid during peak hours or grid disturbances.

B) Transmission

1. Development of a reliable, secure and resilient grid supported by a strong communication infrastructure that enables greater visibility and control of efficient power flow between all sources of production and consumption by 2027.
2. Implementation of Wide Area Monitoring Systems (WAMS, using Phasor Measurement Units, or PMUs) for the entire transmission system. Installation of a larger number of PMUs on the transmission network by 2017 or sooner, as guided by the results of initial deployments. Indigenization of WAMS technology and PMU development and development of custom made analytics for synchrophasor data by 2017.

3. Setting up of Renewable Energy Monitoring Centre's (REMCs) and Energy Storage Systems to facilitate grid integration of renewable generation.

4. 50,000 Kms of optical fiber cables to be installed over transmission lines by the year 2017 to support implementation of smart grid technologies.

5. Enabling programs and projects in transmission utilities to reduce transmission losses to below 4% by 2017 and below 3.5% by 2022.

6. Implement power system enhancements to facilitate evacuation and integration of 30 GW renewable capacity by 2017, 80 GW by 2022, and 130 GW by 2027 - or targets mutually agreed between Ministry of New and Renewable Energy (MNRE) and MoP.

C) Policies, Standards and Regulations

1. Formulation of effective customer outreach and communication programs for active involvement of consumers in the smart grid implementation.

2. Development of state/utility specific strategic roadmap(s) for implementation of smart grid technologies across the state/utility by 2014. Required business process reengineering, change management and capacity building programs to be initiated by 2014. State Regulators and utilities may take the lead here.


4. Policies for grid-interconnection of captive/consumer generation facilities (including renewables) where ever technically feasible; policies for roof-top solar, net-metering/feed-in tariff; and policies for peaking power stations by 2014.

5. Policies supporting improved tariffs such as dynamic tariffs, variable tariffs, etc., including mandatory demand response (DR) programs, starting with bulk consumers by 2014, and extending to all 3-phase (or otherwise defined consumers) by 2017.


D) Other Initiatives

1. Tariff mechanisms, new energy products, energy options and programs to encourage participation of customers in the energy markets that make them “prosumers” - producers and consumers - by 2017.

2. Create an effective information exchange platform that can be shared by all market participants, including prosumers, in real time which will lead to the development of energy markets.

SMART GRID ARCHITECTURE

The European Technology Platform defines the Smart Grid as:

“A Smart Grid 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.”

According to the US Department of Energy:

“A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources.”

![Figure 1.5. DOE Representative Architecture of the Smart Grid design (Architecture 1).](image)
Several types of architecture have been proposed by the various bodies involved in smart grid development. We present two: one from the DOE and one illustrated by Figure 1.5, which shows how the DOE’s proposed smart grid divides into nine areas: transmission automation, system coordination situation assessment, system operations, distribution automation, renewable integration, energy efficiency, distributed generation and storage, demand participation signals and options, and smart appliances, PHEVs, and storage. Figure 1.6 shows how the second architectural framework is partitioned into subsystems with layers of intelligence and technology and new tools and innovations. It involves bulk power generation, transmission, distribution, and end user level of the electric power system. The function of each component is explained in the next section.

FUNCTIONS OF SMART GRID COMPONENTS

For the generation level of the power system, smart enhancements will extend from the technologies used to improve the stability and reliability of the generation to intelligent controls and the generation mix consisting of renewable resources.

Fig :1.6 The intelligent grid (architecture 2).
1 Smart Devices Interface Component

Smart devices for monitoring and control form part of the generation components’ real time information processes. These resources need to be seamlessly integrated in the operation of both centrally distributed and district energy systems.

2 Storage Component

Due to the variability of renewable energy and the disjoint between peak availability and peak consumption, it is important to find ways to store the generated energy for later use. Options for energy storage technologies include pumped hydro, advance batteries, flow batteries, compressed air, super-conducting magnetic energy storage, super-capacitors, and flywheels. Associated market mechanisms for handling renewable energy resources, distributed generation, environmental impact and pollution are other components necessary at the generation level.

3 Transmission Subsystem Component

The transmission system that interconnects all major substation and load centers is the backbone of an integrated power system. Efficiency and reliability at an affordable cost continue to be the ultimate aims of transmission planners and operators. Transmission lines must tolerate dynamic changes in load and contingency without service disruptions. To ensure performance, reliability and quality of supply standards are preferred following contingency. Strategies to achieve smart grid performance at the transmission level include the design of analytical tools and advanced technology with intelligence for performance analysis such as dynamic optimal power flow, robust state estimation, real-time stability assessment, and reliability and market simulation tools. Real-time monitoring based on PMU, state estimators sensors, and communication technologies are the transmission subsystem’s intelligent enabling tools for developing smart transmission functionality.

4 Monitoring and Control Technology Component

Intelligent transmission systems/assets include a smart intelligent network, self-monitoring and self-healing, and the adaptability and predictability of generation and demand robust enough to handle congestion, instability, and reliability issues. This new resilient grid has to withstand shock (durability and reliability), and be reliable to provide real-time changes in its use.
5 Intelligent Grid Distribution Subsystem Component

The distribution system is the final stage in the transmission of power to end users. Primary feeders at this voltage level supply small industrial customers and secondary distribution feeders supply residential and commercial customers. At the distribution level, intelligent support schemes will have monitoring capabilities for automation using smart meters, communication links between consumers and utility control, energy management components, and AMI.

6 Demand Side Management Component

Demand side management options and energy efficiency options developed for effective means of modifying the consumer demand to cut operating expenses from expensive generators and defer capacity addition.

DSM options provide reduced emissions in fuel production, lower costs, and contribute to reliability of generation. These options have an overall impact on the utility load curve. A standard protocol for customer delivery with two-way information highway technologies as the enabler is needed. Plug-and-play, smart energy buildings and smart homes, demand-side meters, clean air requirements, and customer interfaces for better energy efficiency will be in place.