Smart Grid: Concepts and Deployment

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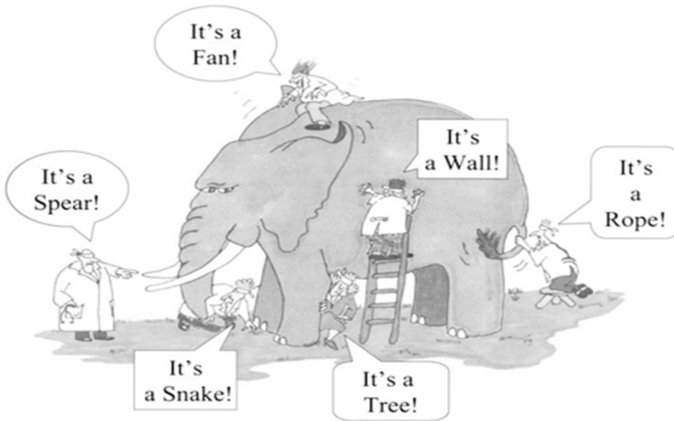
Outline

- Defining the smart Grid
- Need for smart grid
- Smart grid domains
- Enablers of smart grid
- Regulatory challenges
- Smart grid activities in India

What is smart grid?

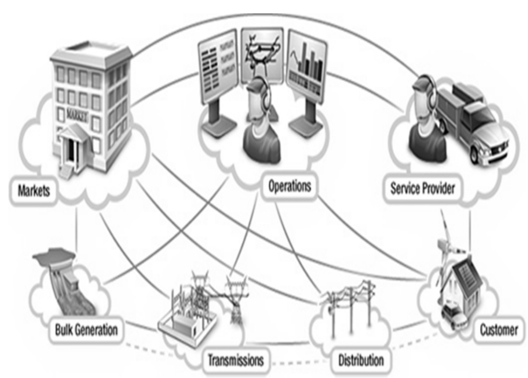


…depends on the way we look at it!

What is smart grid?...contd.

Smarter

- ❑ Generation
- ❑ Transmission
- ❑ Distribution
- ❑ Customer participation
- ❑ Operations
- ❑ Markets
- ❑ Service Providers



Source: http://smartgrid.ieee.org

Overall objective:

Smart/best/optimal utilization of all the available resources.

What is smart grid?...contd.

Definition by National Institute of Standards and Technology (NIST), USA:

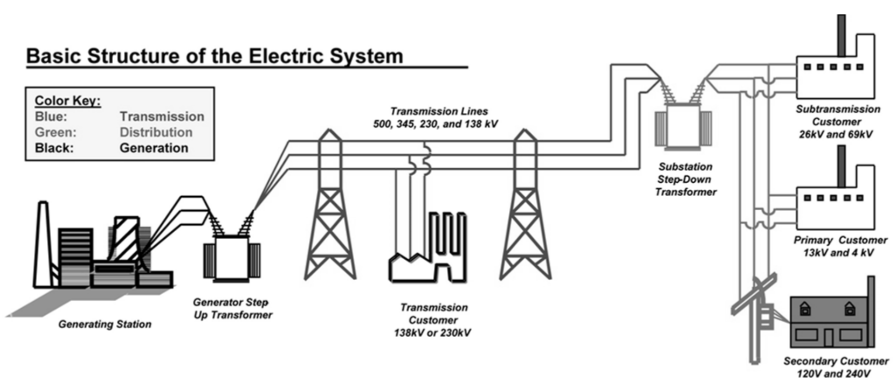
A modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications.

IEEE:

- ❑ Smart grid is a large 'System of Systems', where each functional domain consists of three layers: (i) the power and energy layer, (ii) the communication layer, and (iii) the IT/computer layer.
- ❑ Layers (ii) and (iii) above are the enabling infrastructure that makes the existing power and energy infrastructure 'smarter'.

Need for smart grid

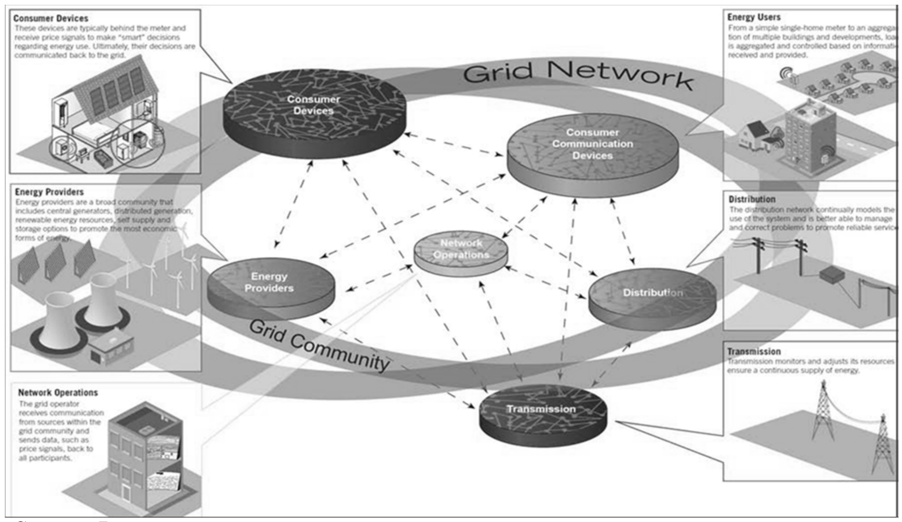
Power system in earlier days



Source: Internet

Need for smart grid...contd.

Modern power system

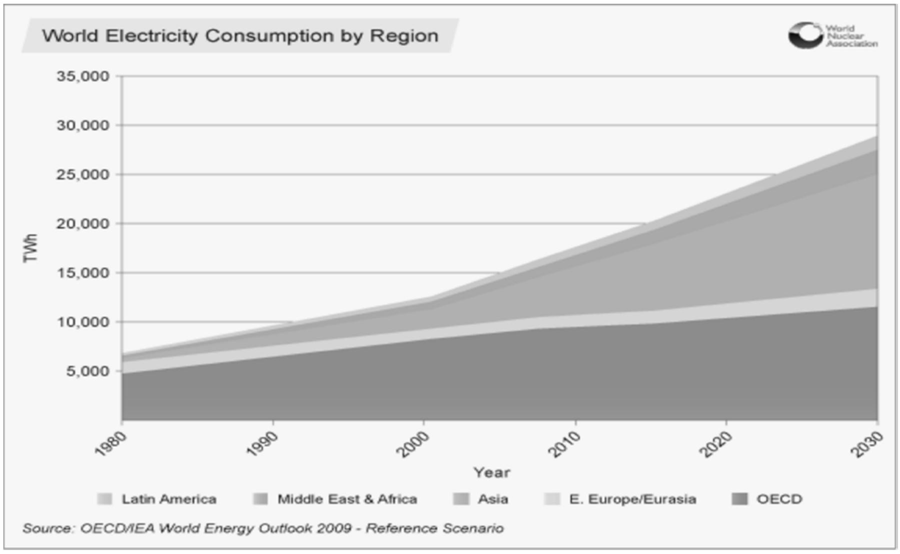


Source: Internet

Characteristics of modern power systems

- Wide geographical spread (due to typical large distance between major load centres and conventional sources of energy).
- Large number of interconnections (due to political, economic, environmental, reliability, and stability issues).
- Rapid growth in the demand of electricity (due to increase in population, standard of living, development of townships).
- Power system components are being operated closer to their designed limits (more investment needed in the electrical infrastructure).
- High penetration of renewable energy sources (intermittency, relay coordination, power quality, system stability).
- Competitive electricity market (needs real time monitoring and strict regulation).

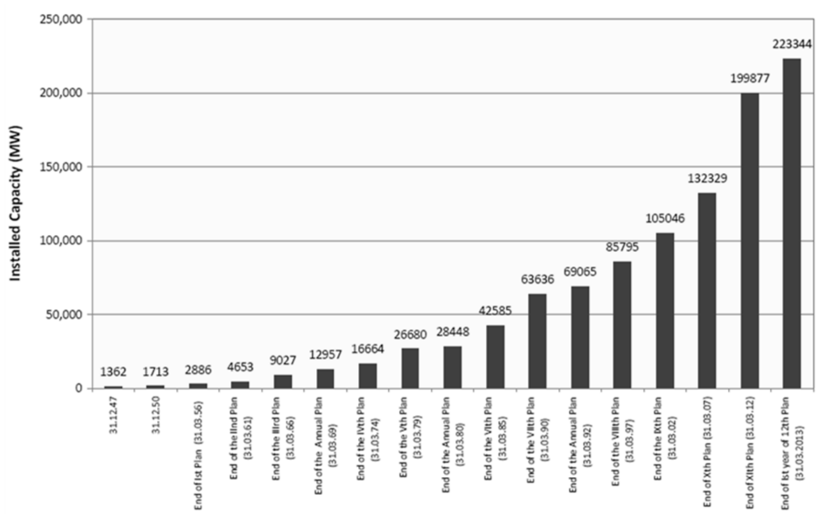
Growth in the electricity sector



Source: Internet

Growth in the electricity sector in India

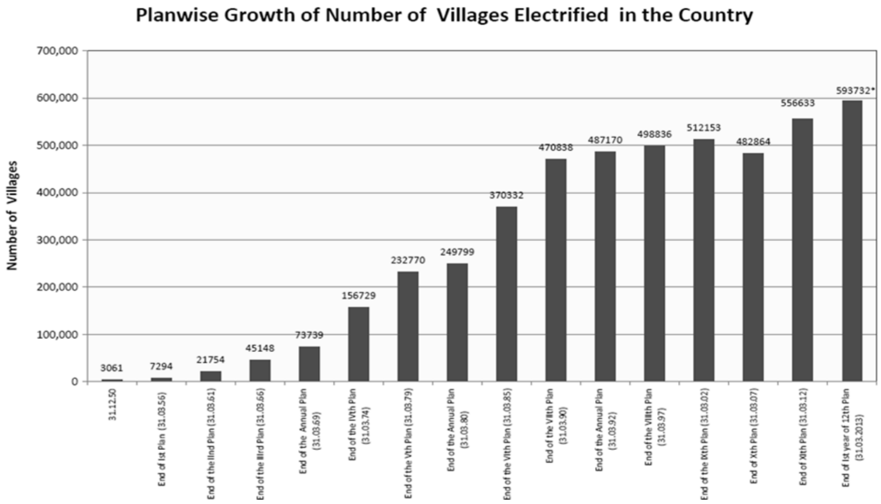
Installed generating capacity



Source: http://www.cea.nic.in

Growth in the electricity sector…contd.

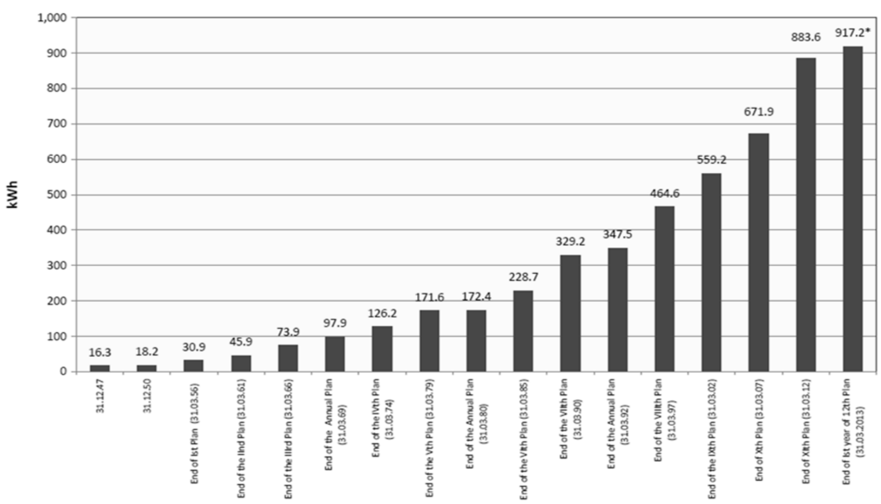
Number of villages electrified



Source: http://www.cea.nic.in

Growth in the electricity sector…contd.

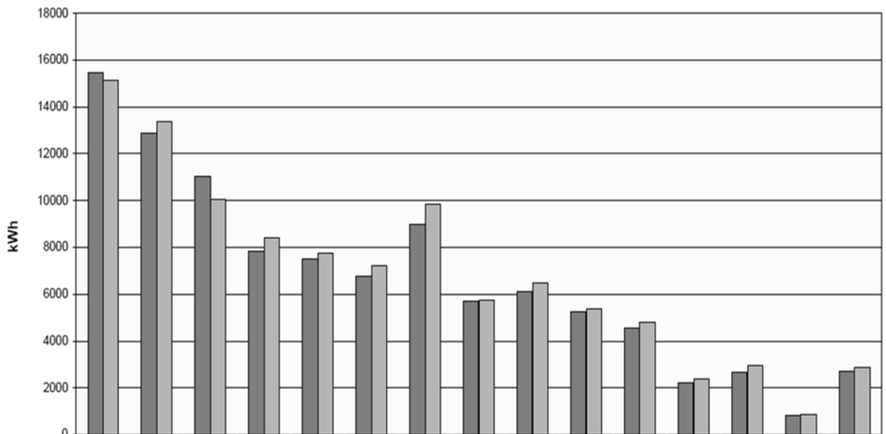
Per capita consumption of electricity



Source: http://www.cea.nic.in

Growth in the electricity sector...contd.

Per capita consumption in major economies in the world



	Canada	USA	Australia	Japan	France	Germany	Korea	UK	Russia	Italy	South Africa	Brazil	China	India($)*	World
2009	15467	12884	11038	7833	7494	6781	8980	5693	6133	5271	4532	2201	2648	819	2730
2010	15145	13361	10063	8399	7756	7217	9851	5741	6460	5384	4803	2384	2942	884	2892

Source: http://www.cea.nic.in

Smart grid domains: generation

- ❑ Co-existence of various types of renewable and non-renewable generating technologies, such as coal, hydro, nuclear, solar, biomass, geothermal, etc.
- ❑ System operator has to coordinate the operation of the generation plants, and ensure the stable and secure operation of the system.
- ❑ Wide-area measurement system (WAMS) enabled by communication technologies need to be used to control the operation of the generating stations. WAMS based power system stabilizer is one such example.
- ❑ Communication infrastructure needs to be in place between the generating facilities and the system operator, electricity market, and the transmission system.

Smart grid domains: transmission

- Energy-efficient transmission network will carry the power from the bulk generation facilities to the power distribution systems.
- Communication interface exists between the transmission network and the bulk-generating stations, system operator, power market, and the distribution system.
- The transmission network needs to be monitored in real-time, and protected against any potential disturbance.
- The power flow and voltage on the lines need to be controlled in order to maintain stable and secure operation of the system.
- An important task of the system operator is to ensure optimal utilization of the transmission network, by minimizing the losses and voltage deviations, and maximizing the reliability of the supply.

Smart grid domains: distribution

- Substation automation and distribution automation will be the key enablers for the smart distribution systems.
- Increasing use of distributed energy resources (DERs) will be an important feature of future distribution systems.
- Distribution system operator typically controls the distribution system remotely. Communication infrastructure to exchange information between the substations and a central distribution management system (DMS) therefore should be in place.
- An important job of the distribution system operator is to control the DERs in a coordinated way to ensure stability and power quality of the distribution system.
- Information exchange between the distribution system operator and the customers for better operation of the distribution system is a new feature of the smart distribution systems.

Smart grid domains: customers

- Customers can be classified into three main categories: residential, commercial, and industrial.
- In smart grids, customers are going to play a very important role through demand response. By peak-load shaving, valley-filling, and emergency response, customers are going to play an active role in better operation of the distribution system
- Building or home automation system will monitor and control the power consumption at the consumer premises in an intelligent way.
- Proper communication infrastructure will be required for the consumers to interact with the operators, distribution systems, and the market.

Smart grid domains: operations

- Smart grid operations require communication interface with the bulk generating facilities, transmission system, substation automation, distribution automation, DMS, consumers, and the market.
- Metering, recording, and controlling operations come under the purview of the smart grid operations.
- Real-time information exchange with the power market needs to be established in order to implement power trading and scheduling.
- The operators need to interact with various service providers for ensuring proper functioning of the smart grid.
- Information exchange with the consumers or prosumers is they key for the operators to implement the so-called demand management system.

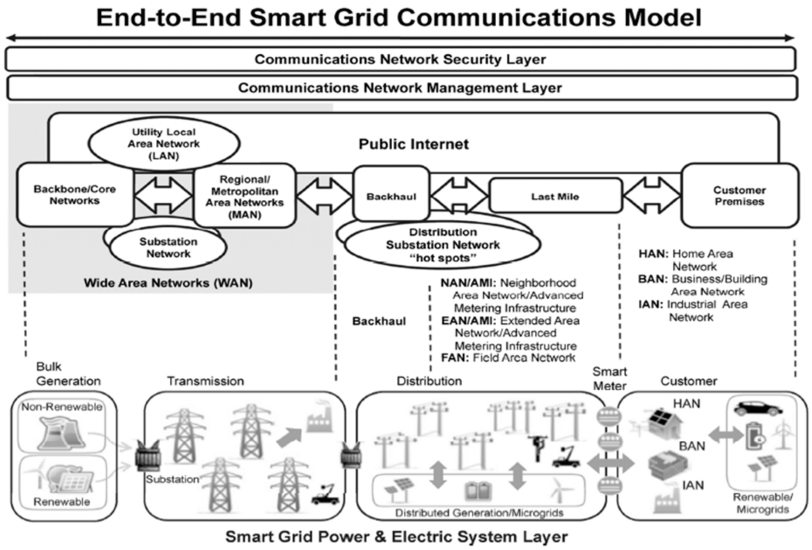
Smart grid domains: markets

- Smart grid power market needs to develop, keeping in mind all the objectives of the smart grid.
- The communication infrastructure integrating the bulk generation, transmission, distribution, consumers, markets, and service providers is the key to the success of the power market in a smart grid.
- Appropriate regulatory policies need to formulated for seamless integration of the various domains, including the storage and DER aggregators into the smart grid market.
- The pricing information has to be made available online for shorter intervals (hours or even minutes).

Smart grid domains: service providers

- Various service providers will emerge, as the smart grid business model matures.
- Communication interface with the operator, market, and consumers will be needed for the service providers.
- Examples of services:
  - Forecasting for renewable generation.
  - Billing and customer complain management.
  - Building and home management.
  - Installation and commissioning services.
  - Account management.

Enablers of Smart Grid: Communication



Source: IEEE Standard 2030-2011

Enablers: Measurement and sensing

- ❑ Sensing and measurement system is the backbone of a Smart Grid.
- ❑ Smart meters and the associated advanced metering infrastructure (AMI) has to be in place to support monitoring, control, protection, and decision making functions.
- ❑ High-resolution real-time measurements will enable optimal usage of the available resources, avoid congestions, assist market operations, and make demand side management possible.
- ❑ Emerging technologies, such as the synchrophasor technology is already being used in modern power systems.
- ❑ Phasor measurement units (PMUs) can provide time-synchronized measurements from distant locations, and make possible the design of a wide area monitoring, protection, and control (WAMPAC) system.

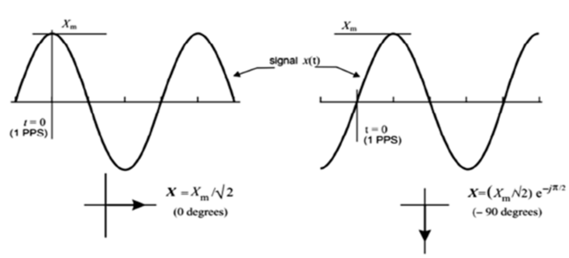
Enabler…contd.:Advanced metering infrastructure (AMI)

- ❑ Smart meters at user end
- ❑ Smart meter network
    - ➢ Zigbee
    - ➢ Global System for Mobile communication (GSM)
    - ➢ Broadband over Power Line (BPL)
    - ➢ Internet/Intranet
    - ➢ WiFi
- ❑ Meter data concentration unit
- ❑ Meter Data Management System (MDMS)
- ❑ Integration of MDMS with SCADA
- ❑ IT infrastructure for the MDMS

Enabler…contd.:Synchrophasor measurements

<u>Synchrophasor definition</u>

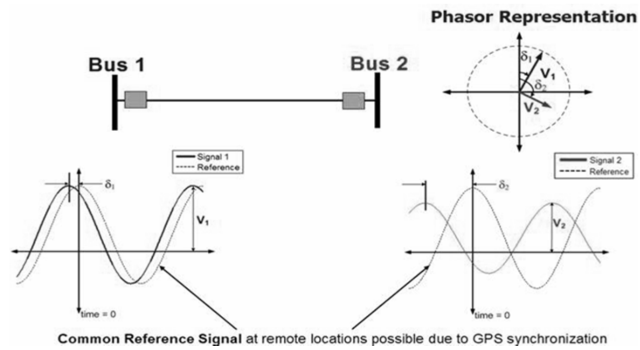
1 pps time signals are obtained from GPS. As shown in Figure, phase angle of a sinusoidal signal x(t) will be taken as 0◦, if the peak of the signal coincides with the UTC seconds rollover. The phase angle is taken as 90◦ if the positive zero-crossing of the signal coincides with the UTC seconds rollover.



Convention for synchrophasor representation

Enabler…contd.:Phasor measurement units (PMUs)

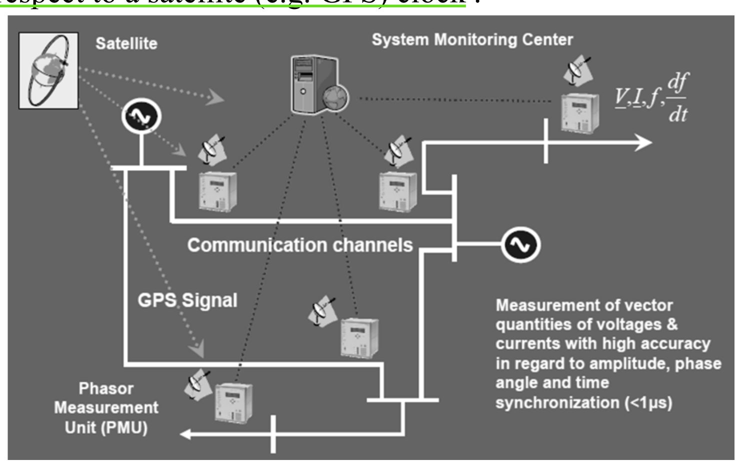
- Phasor represents a sinusoidal signal with a magnitude and a phase angle (with respect to a reference).
- Phasor measurement technology enables measurement of voltage and current phasors with respect to a reference signal from a satellite clock.



Source: http://www.phasor-rtdms.com/

Enabler…contd.:Wide area measurement system (WAMS)

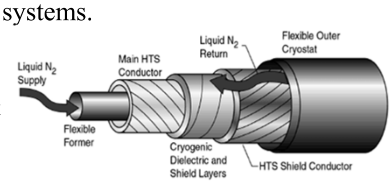
Measurements from widely dispersed locations are synchronized with respect to a satellite (e.g. GPS) clock .



Source: Internet

Enablers: Advanced components

- **Advanced use of power electronics.**
  - Flexible alternating current transmission system (FACTS) devices for better voltage control, power quality improvement, reactive power balance, stability improvement, and transfer of power over long distances.
  - High voltage direct current (HVDC) system for back-to-back and long-distance power transmission, improving system stability.
- **Superconducting devices.**
  - Superconducting wires for highly efficient and reliable transfer of power, improvement of power quality.
  - High temperature superconducting (HTS) cables for transfer of bulk power at lower voltage and high current; lowers cost of HVDC terminals by 20-50%; huge potential for future power systems.
  - Superconducting magnetic energy storage (SMES), superconducting synchronous condensers, fault current limiters, high-efficiency motors and generators.



HTS cable. Source: Internet

Advanced components…contd.

- **Advanced generation technologies.**
  - Improvement in the existing technologies for bulk generation.
  - Developments in the distributed energy resources (DER) technologies (typically in 3 kW-10 MW range), using advances in chemistry, materials, and power electronics.
  - Examples of DER: microturbine, fuel cell, solar photovoltaic (PV), wind turbine, diesel generators, and gas turbines.
- **Advanced storage technologies.**
  - Sodium sulfur (NaS) battery: highly efficient (~89%), economic, large energy storage capacity, can be used for power quality, peak shaving.
  - Vanadium redox flow battery (VRB): larger storage, modular design, can be used for peak shaving, stability improvement of the grid.
  - Ultracapacitors: stores energy like a battery, discharges quickly like a capacitor.
  - Superconducting magnetic energy storage (SMES): low loss, fast response, use for power quality improvement and stability enhancement.

Advanced components…contd.

- **Composite conductors.**
  - High temperature operation, increased amperage, reduced sag.
  - Examples: Aluminum Conductor Composite Core (ACCC™) Cable, Aluminum Conductor Composite Reinforced (ACCR) Cable, Annealed aluminum, steel supported, trapezoid cross section conductor wire (ACSS/TW).
- **Grid-friendly appliances.**
  - Voltage and frequency-sensing appliances will assist in stabilizing the grid following a disturbance, enable demand response.
  - Example: appliances, such as heaters, air conditioners, washing machines, dryers etc. can be switched on or off to shave peak load or fill valley load.
  - This will enable customers to participate effectively in making the grid smarter.

Enablers: Advanced control methods

- **Better control of bulk generation.**
  - Advanced microelectronics, better control for the generators.
  - Use of wide area signals to mitigate power oscillations (power system stabilizers), enhance transient stability of the generators.
- **Real-time monitoring and control of power system stability.**
  - Use of wide area measurement system for monitoring and control of angular, frequency, and voltage stability.
  - Distributed control, self-healing of the grid following a disturbance.
- **Advanced control of distribution systems.**
  - Stability and control of microgrids under grid connected and islanded mode.
  - Appropriate load sharing and optimal usage of energy mix at the distribution level.

Regulatory challenges

- Many of the utilities are doing well with their current practice. It is hard to convince them about the benefits of smart grid.
- Energy efficiency is one of the benchmarks of smart grid. This does not necessarily lead to economic efficiency, not at least in the short-term.
- For obvious reasons, smart grid technologies are implemented in phases. The overall benefit of smart grid may become apparent only after coordinated utilization of these technologies.
- Policies to reward and incentivize investment in smart grid need to be formulated.
- Mechanisms need to be worked out to involve various stakeholders. Promoting demand response is one such example.

Regulatory challenges…contd.

- Encouraging system operator and utilities to play a more active role in addressing future economic, technical, and social challenges.
- Forming a long-term clear-cut policy for implementation of smart grid.
- Policies for integration of electric vehicles, demand response, and renewable energy systems into the existing market.
- We have to be ready to handle a huge amount of data, coming from smart meters, phasor measurement units, intelligent electronic devices, smart remote terminal units. Data protection issues need to be addressed.
- Smart grid standardization, to ensure seamless integration of various technologies and equipment from different vendors.

Smart Grid activities in India

- **India Smart Grid Forum (ISGF): launched by Union Power Minister on May 26, 2010.**
  - A non-profit voluntary consortium of public and private stakeholders with the prime objective of accelerating development of Smart Grid technologies in the Indian Power Sector.
- **India Smart Grid Task Force (ISGTF).**
  - An inter ministerial group and will serve as Government's focal point for activities related to Smart Grid.
  - Distributed control, self-healing of the grid following a disturbance.
- **Many utilities have started individual activities at different levels.**
- **Several pilot city projects are being funded by MOP, and coordinated by the Ministry of Urban Development**

Smart Grid activities in IIT Kanpur

- Power Engineering and Communication Systems group actively engaged in Smart Grid related research.
- Some of the major research areas:
  - Synchrophasor applications in power system monitoring, stability, control, and protection.
  - Renewable energy integration.
  - Electricity markets for the Smart Grid.
  - Stability, control, and protection of AC and DC microgrids.
- Going to set up a Smart City prototype in the IIT Kanpur campus. The project is funded by the Ministry of Power and IIT Kanpur.
- Real-time digital simulation facility and synchrophasor lab.

Conclusions

- Smart Grid is characterized by the integration of communication networks and IT infrastructure with the power and energy layer.
- It requires seamless integration of different types of bulk energy sources, distributed energy sources, transmission and distribution systems, communication systems, and measurement systems.
- Modular integration approach and open architecture need to be adopted.
- Managing the large amount of information and ensuring its security will be a big challenge. Cyber-security and cloud computing applications are bound to get increased importance.
- Experts from various domains need to be involved.

Some references

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