Smart Grid
The Future Distribution Network

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Current Power System

Existing Distribution Grid
• Have seen little change
  – Mostly radial
  – Mostly unidirectional power flows
  – Passive in operation.
• Their primary role is energy delivery to end-user

What is New?

Renewable Energy Penetration

Deregulation of energy market
Customers Demands

- Cost options
- Reduced outages
- Energy Options

New sensors and control technologies

Wind Capacity Worldwide

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<tr>
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<th>2006</th>
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Smart Grid

**Smart Grid Objectives**

- **Accessible:** granting access and capability for bidirectional flow to all customers.
- **Flexible:** fulfilling customers’ needs whilst responding to the changes and challenges ahead
- **Reliable:** assuring and improving security and quality of supply
- **Economic:** providing best value through innovation and efficient energy management.

**What to Expect?**

- A proportion of the electricity generated by large conventional plants will be displaced by
  - distributed generation
  - renewable energy sources
  - energy storage
  - demand response
  - demand side management

**What can be Achieved by the Smart Grid?**

- Reduction in transmission congestion
- Reduced **blackouts** and forced outages
  - “power outages and fluctuations cost U.S. businesses and consumers $30 billion each year.” DOE
- Reduction in restoration time
- **Self diagnosis** and self healing

**What can be Achieved by the Smart Grid?**

- Peak demand **shaving**
- Increased system **capacity**
- Increased **security** and reduced vulnerability
What can be Achieved by the Smart Grid?

• Reduction is some **power quality** problems due to improved power flow

• Increase **environmental benefits**

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Technology needed to implement the Smart Grids

• Energy Storage
• Advanced Metering and Sensors
• Grid friendly Plug-in Hybrids
• Grid friendly loads
• Smart houses
• Substation Automation
• Distribution Automation
• Communications
• Demand Response
• Web Services and Grid Computing
• Weather Prediction
• Advanced Conductors
• Advanced distributed control

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Smart House

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Grid Friendly™ Appliances (GFAs)

• Grid Friendly Appliances sense grid frequency excursions & control appliances to act as spinning reserve
• No communications required!
• Used only with switchable loads
Grid Friendly™ Appliances (GFAs)

Rob Pratt
Pacific Northwest National Laboratory

Bus 25 frequency

@ t = 1 sec: loads +5%
@ t = 40 sec: loads +15%

from Trudnowski et al. IEEE PES. 2005.
(http://gridwise.pnl.gov/docs/pnnlsa44073.pdf)

Demand Elasticity

Energy Storage

Energy Storage

Energy Storage

Energy Storage

Energy Storage

Energy Storage

Energy Storage

Energy Storage
Advantages of Energy Storage

Pumped-Hydro Storage (PHS)

Compressed Air Energy Storage (CAES)
- Pressurize air into an underground reservoir (salt cavern, abandoned hard rock mine, or aquifer)
- 100MW in single unit sizes
- Installations
  - A 290 MW unit in Germany (1978)
  - A 110 MW unit built in McIntosh, Alabama in 1991.
  - A 2,700 MW is being built in Norton, OH

Batteries
- Sodium Sulfur and Lithium ion
  - 10MW facility in Chino, CA
  - 20 MW in Puerto Rico
  - ... ...
- Vanadium Redox flow (regenerative fuel cell)
  - 15 MW, 120MWh in UK
  - 12 MW, 120 MWh in operation by the Tennessee Valley Authority (TVA)
  - ... ...

Flywheels
- 25kWh rating – 20MW system is in operation
Super Capacitors (Ultra-Capacitors)
• High energy, high power density (15kW/kg)

Superconducting Magnetic Energy Storage (SMES)
• Up to 3 MW units
• Store energy in the magnetic field created by the flow of direct current in a superconducting coil

Other Storage Methods
• Thermal storage
• Hydrogen Storage
• ... ...

Plug-In Hybrid Vehicles

Plug-In Hybrid: Prediction
• If Light Duty Vehicle (LDV) in the USA are plug-in hybrids, and if 70% of their energy are from electricity
  – Petroleum consumption will be reduced by 50%
  – Utilities would add approximately 1 TWh to their current generation
    • This is over 25% of the total U.S. annual generation in 2006.
  – Utilities will have a tremendous surge in demand between 5-7PM

Plug-In Hybrid: Impacts
• Heavily loaded system most of the time
• If the heavy demand is not matched by new generation
  – less reserve capacity is available
  – maintenance occurs more frequently
  – maintenance is more difficult to schedule
Plug-In Hybrid: Ideas

- Vehicle-to-grid concepts
  - Could provide additional capacity by reversing the power flow from the battery to the grid.

Why Advanced Metering

- "the nation’s energy delivery system has not adopted and made use of advanced data collection, data management and communication technologies that will be required to meet the needs of the dynamic energy marketplace"
  - "The Critical Role of Advanced Metering Technology in Optimizing Energy Delivery and Efficiency." Itron report to DOE

Advanced Metering and Sensors

- Goals:
  - Data matching system capacity to load requirements
  - Load management & control capability
  - Immediate outage detection
  - Accurate load forecasting
  - Enhanced distribution system optimization
  - Tamper detection and theft identification
    - "Theft of electricity alone in the US is $1-10 billion Annually"
  - Eliminates the need to access customer property

Usage of Advanced Metering with Some Capabilities

- Source: FERC Survey
Communications

Advantages of BPL

• To allow the implementation of self-healing
  – Instant identification of system problems
  – Fast isolation of problem
  – Fast system restoration
• To help support widespread use of distributed generation
• To help better control of appliances and equipment
• To help customers manage their energy use
• To provide internet connection to customers

Web Based Grid Computing

• Computing model that take advantage of several networked computers.
• Integrate grid operations with other technologies such as
  – Outage Management
  – Condition Based Maintenance
  – System Planning
  … …

Security Challenges

• The grid must be made secure from cascading damage.
  – Pathways for attack must be sealed off.
  – Under attack conditions, the system must be sectionized and reconfigured
• Critical controls and communications must be made secure from penetration by hackers and terrorists.

Communication: Challenges

• Current BPL doesn’t allow the signals to travel long distances
  – Transformers bypass
  – BPL repeaters
• Power line coupler with bypass capabilities are needed
  – Transformer bridges (wired or wireless)
Demand Management

• **Incentive-based** direct load control
  – interruptible/curtailable rates
  – emergency demand response programs
  – capacity market programs
• **Time-based** rates:
  – time-of-use rates
  – critical-peak pricing
  – real-time pricing

Existing demand response contribution

- [Graph showing the contribution of different sectors to demand response](#)

Source: FERC Survey

Note: Other reliability region includes Alaska and Hawaii.
## Wind Forecasting

**Regional vs local forecasting**
- **Synoptic scale** (large scale) meteorology: Air masses, fronts, and pressure systems are not accurate indicators for local conditions.
- **Mesoscale** (local scale) meteorology: Effects of topography, bodies of water, the urban heat island are needed for wind farms.

**Short vs long term forecasting**
- No accurate long term forecasting is available
- The **nowcasting** (0-6hr) is more accurate for weather stable regions

**Ensemble forecasting**
- Average method produce better results
- Enhanced prediction by optimizing the weights of the ensemble

**Challenges**
- Regional data is used to forecast local conditions
- Insufficient local sampling
- Topography effects are hard to consider
- Errors in the observations are very high
- Knowledge of features is weak
- ... ...

## Solar Power Density Forecasting

**Challenges**
- Concentration and type of aerosols
- Humidity
- ... ...

## Advanced Conductors

**Thermal Capacity**
- Advanced Aluminum Conductor Composite can increase thermal capacity by a factor of 3

**Reduced Losses**
- Yttrium Boron Copper Oxide can reduce lines losses (10 times less AC losses)

**Fault Limiter**
- Yttrium Boron Copper Oxide wire can limit fault currents
Thank You