An Introduction to Smart Grid

CS 687
University of Kentucky
Fall 2015

Outline

• Why Smart Grid?
• What is Smart Grid?
• Key Technologies of Smart Grid
• NIST Framework
• Examples
The Traditional Power Grid

Nationwide GRID

http://oncor.com/images/content/grid.jpg

Western Interconnection

Eastern Interconnection

Texas Interconnection

Northern Interconnection

http://oncor.com/images/content/grid.jpg
The case for REVITALIZATION
The case for REVITALIZATION

The story goes like this:

• If Alexander Graham Bell were somehow transported to the 21st century, he would not begin to recognize the components of modern telephony – cell phones, texting, cell towers, PDAs, etc.
• while Thomas Edison, one of the grid’s key early architects, would be totally familiar with the grid.

Why Smart Grid?

• RELIABILITY: There have been five massive blackouts over the past 40 years, three of which have occurred in the past nine years. Today’s electricity system is 99.97 percent reliable, yet still allows for power outages and interruptions that cost Americans at least $150 billion each year.
• EFFICIENCY: If the grid were just 5% more efficient, the energy savings would equate to permanently eliminating the fuel and greenhouse gas emissions from 53 million cars.
• SECURITY: The interdependencies of various grid components can bring about a domino effect.
Why Smart Grid? (cont)

- **ENVIRONMENT/CLIMATE CHANGE:** The United States accounts for only 4% of the world’s population and produces 25% of its greenhouse gases. Half of our country’s electricity is still produced by burning coal.
- **GLOBAL COMPETITIVENESS:** Germany is leading the world in the development and implementation of photovoltaic solar power. Japan has similarly moved to the forefront of distribution automation through its use of advanced battery storage technology. The European Union has an even more aggressive “Smart Grids” agenda.

What Is Smart Grid? (NIST)

- By integrating an end-to-end, advanced communications infrastructure into the electric power system, a Smart Grid can provide consumers near real-time information on their energy use, support pricing that reflects changes in supply and demand, and enable smart appliances and devices to help consumers avoid higher energy bills.
- A Smart Grid uses information and communication technology to make the power grid more efficient, reliable, secure, and resilient while minimizing costly investments in new generation capacity.
What Is Smart Grid? (NIST)

A more intelligent grid can

- support demand response (user participation)
- reduce the duration and frequency of power outages
- lower generation requirements by reducing inefficiencies in energy delivery
- facilitate efficient charging of electric vehicles
- better integrate wind and solar resources
- provide more effective management of distributed generation and storage.

Characteristics of Smart Grid (DoE)

- Enables informed participation by customers
- Accommodates all generation and storage options
- Enables new products, services, and markets
- Provides the power quality for the range of needs
- Optimizes asset utilization and operating efficiently
- Operates resiliently to disturbances, attacks, and natural disasters.
A Consumer’s Perspective

Consumer participation [1]

Smart House

Added green power sources
Plug-in hybrid electric cars
Real-time and green pricing signals
High-speed, networked connections
Smart thermostats, appliances and in-home control devices
Customer interaction with utility

http://www.worldchanging.com/smarthouse.jpg
Demand Response

• Keep generation costs as low as possible
• Generation costs differ based on:
  – Construction costs
  – Fuel
    • Renewables
    • Hydro
    • Coal
    • Nuclear
    • Natural Gas
  – Purchases from foreign utilities
Resource Dispatch

Peak Shaving

• Demand side management
  – Direct load control
    • Utility control of consumer appliances
• Dynamic pricing of electricity
  – Time of day rates
  – Time of use rates
  – Real time pricing
• Energy Storage
  – Pumped hydro
  – Battery
Direct Load Control

• Utility control of consumer appliances
  – Water heaters
  – HVAC / Thermostats
  – Hot tub and pool pumps
  – Commercial refrigerators
  – Compressed air

• Participation incentive
  – Water heaters: $10 annually per unit
  – HVAC - Customer choice:
    • $5 / month from June through September
    • Programmable thermostat

Dynamic Pricing

• Time of day rates
  – More expensive during peak hours (daytime)
  – Less expensive during off-peak hours (night time)

• Time of use rates
  – Bill based on actual costs during time of consumption

• Real time pricing
  – Firm price for energy posted in advance
Distributed Generation

- Most often renewable energy sources
- Includes energy storage systems
- Generation at load centers
  - Integration with utility infrastructure
  - Distribution level voltages
- Reduced system losses
- Defer / delay construction
- Micro-grid concept

Energy Storage

- Charge during off-peak hours; discharge during on-peak hours
- Store renewable based energy
- Provide backup power
- Respond to and mitigate voltage fluctuations
- Provide uninterruptable power
- Ride through momentary outages
- Defer / delay utility infrastructure construction
Energy Storage Technologies

• Pumped hydro
  – Two reservoirs at two different elevations
  – Produce hydro power during on-peak hours
  – Pump water back to upper reservoir during off-peak hours
  – Use of nuclear or coal power for pumping

• Compressed air
  – Same principle as pumped hydro
  – Use of underground caverns

• Flywheels
  – Short duration
  – Transportation?

• Utility scale battery systems
• Electric vehicles (cars)?

Pumped Hydro

Diagram of TVA Raccoon Mountain

Seawater Pumped Hydro
Okinawa, Japan

LaMuela, Spain (635 MW)
Utility Scale Battery Systems

- **American Electric Power**
  - US DOE Sandia National Lab
- **4 MW**
  - 80, 50 kW units
  - 4 MW continuous for 8 hours
  - 25 MWh
- **NAS sodium sulfur battery system**
- **Commissioned March 2010**
- **Gonzales Substation in Texas**
- **$25M**
  - Remember: It doesn’t produce power!

Residential Scale Battery Systems

- Residential with or without DG
- Though distributed, aggregated with over-riding control system
- Responds to substation demands
- Both pad mount and pole top units available
Key Technologies

https://www.sgiclearninghouse.org/Technologies

• Integrated communications
  – Fast and reliable communications for the grid
  – Allowing the grid for real-time control, information and data exchange to optimize system reliability, asset utilization and security
  – Can be wireless, powerline or fiber-optics
  – For wireless
    • Zigbee
    • WiMAX
    • WiFi

[1]

Key Technologies

• Integrated communications (cont.)

  • Broadband over Powerlines
    — Provide for two-way communications
  • Monitors and smart relays at substations
  • Monitors at transformers, circuit breakers and reclosers
  • Bi-directional meters with two-way communication

[1]
Key Technologies

• Sensing and measurement
  – Smart meter technology, real time metering of:
    • Congestion and grid stability
    • Equipment health
    • Energy theft
    • Real time thermal rating
    • Electromagnetic signature measurement/analysis
    • Real time pricing
  – Phasor measurement units (PMU)
    • Real time monitor of power quality
    • Use GPS as a reference for precise measurement

Key Technologies

• Advanced components
  – Flexible AC transmission system devices
  – High voltage direct current
  – Superconducting wire
  – High temperature superconducting cable
  – Distributed energy generation and storage devices
  – Composite conductors
  – “Intelligent” appliances
Key Technologies

• Power system automation
  – Rapid diagnosis and precise solutions to specific grid disruptions or outages
  – Distributed intelligent agents
  – Analytical tools involving software algorithms and high-speed computers
  – Substation Automation

Key Technologies

• Improved Interfaces and Decision Support
  – Consumer gateway and portal
  – Grid friendly appliance controller
  – Power transmission/distribution analysis software
  – Distributed Energy Resources Controller
  – Microgrid control software
IEEE P2030 Task forces

• IEEE P2030 project defined three task forces:
  – TF1: Power Engineering Technology
  – TF2: Information Technology
  – TF3: Communications Technology

NIST Framework
Domains and Actors

- **Customers** -- The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: residential, commercial, and industrial.

- **Markets** -- The operators and participants in electricity markets.

- **Service Providers** -- The organizations providing services to electrical customers and utilities.

Domains and Actors (cont)

- **Operations** -- The managers of the movement of electricity.
- **Bulk Generation** -- The generators of electricity in bulk quantities. May also store energy for later distribution.
- **Transmission** -- The carriers of bulk electricity over long distances. May also store and generate electricity.
- **Distribution** -- The distributors of electricity to and from customers. May also store and generate electricity.
NIST Framework

End-to-End Smart Grid (High-Level Taxonomy)
"End-to-End" Smart Grid
(High-Level Taxonomy)

Smart Grid Applications Layer

Integrated Enterprise-Wide Advanced Control Systems

Utility Control and Management System (UCMS)/Application 1

Distributed generation and storage data

Distributed generation and storage data

Distributed generation and storage data

Demand Response

Home appliance data and control

Application 1

Application 1

Application 1

Application 1

Application 1

Application 1

Communication Layer

LAN

WAN

WLAN

FiWi

MAN

Home Area Network (HAN)

Network Gateway

Smart Meter

Power Layer

Generation

Transmission

Substation

Distribution

Retail

Building

Distributed Generation and Storage
Current Example applications

• Austin, Texas, 1st Smart Grid city in US


Current Example applications

• Xcel Smart City in Boulder

http://smartgridcity.xcelenergy.com
Current Example applications

• Energy Smart Miami

Smart Grid
- Smart appliances can shut off in response to high frequency blackouts.
- Disturbances are detected, and blackouts are localized to prevent urban areas from being isolated.
- Energy generated in peak times can be stored for later use.
- Generator: Energy from small generators and fuel cells helps overall demand on the grid.
- Houses: Smart homes can turn off appliances when necessary.
- Solar panels: Solar energy is used to power homes.
- Control power plant: Power is distributed to different areas.


Current Example applications

• GE “Plug into the Smart Grid”

PlugIntoTheSmartGrid.com

http://ge.ecomagination.com/smartgrid