Topic 2: Introduction to Smart Grid

Department of Electrical & Computer Engineering
Texas Tech University

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Agenda

- Smart Grid: Definition
- Smart Grid: Applications / Benefits
- Smart Grid in the United States
  - Government and Industries
  - Current Projects
  - Priority Areas
- Smart Grid Standards

Course Overview

Q: What is Smart Grid?

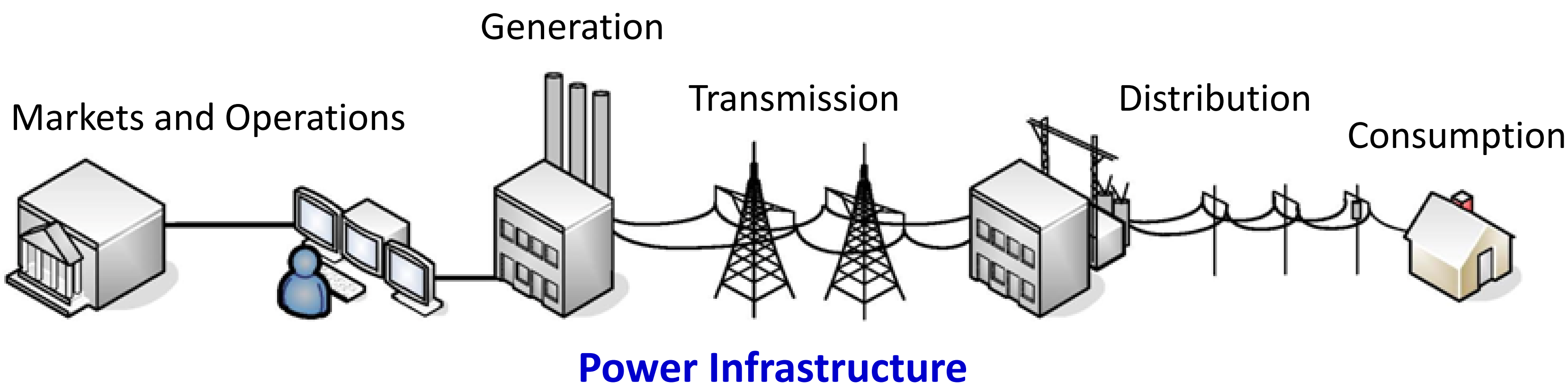
Course Overview

Q: What is Smart Grid?

Short Answer: Smart Grid = IT + Electric Grid

What is Smart Grid?

- Traditional Power Grid:

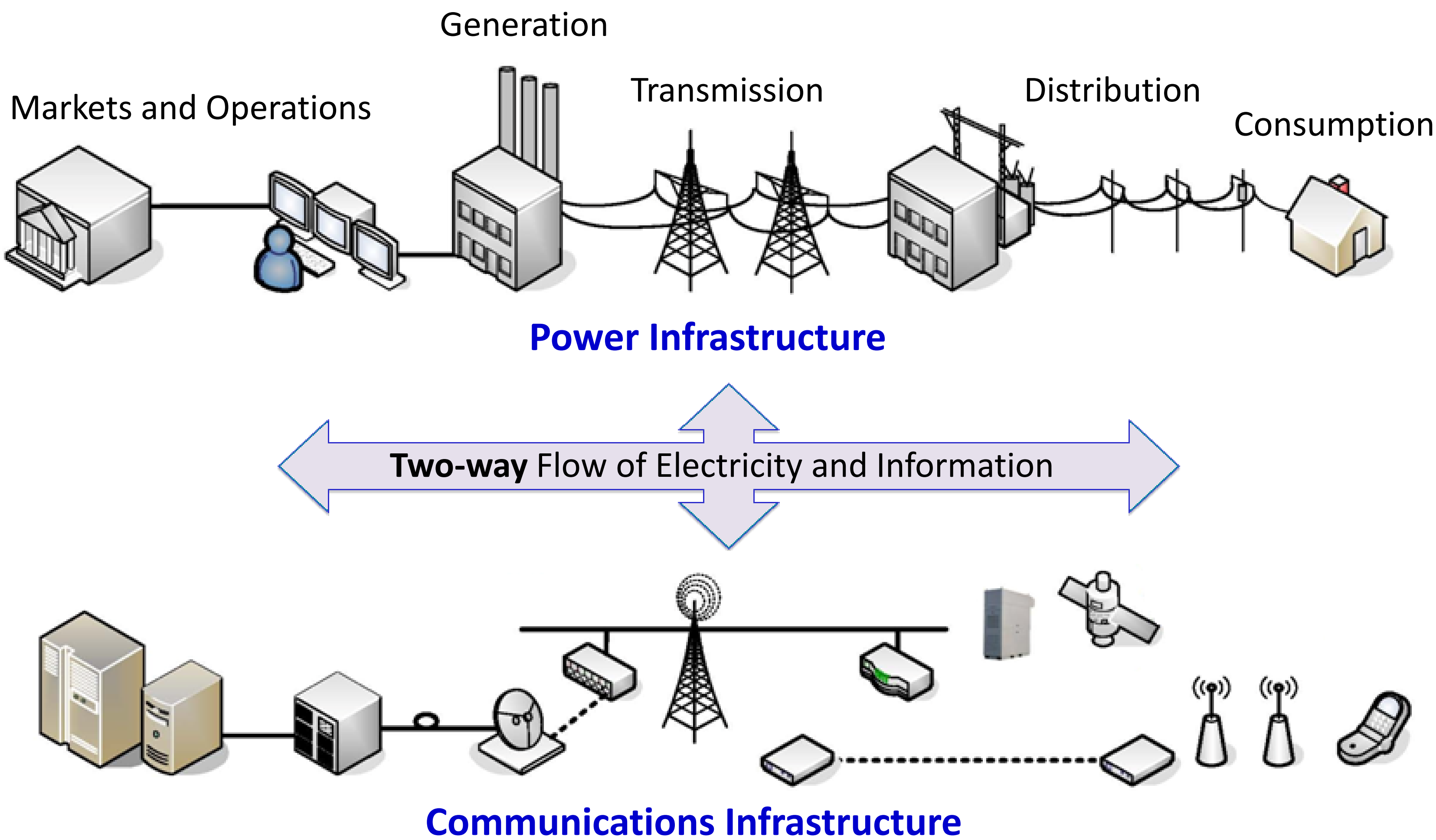


One-way flow of electricity

Centralized, bulk generation
Heavy reliance on coal and oil
Limited automation
Limited situational awareness
Consumers lack data to manage energy usage

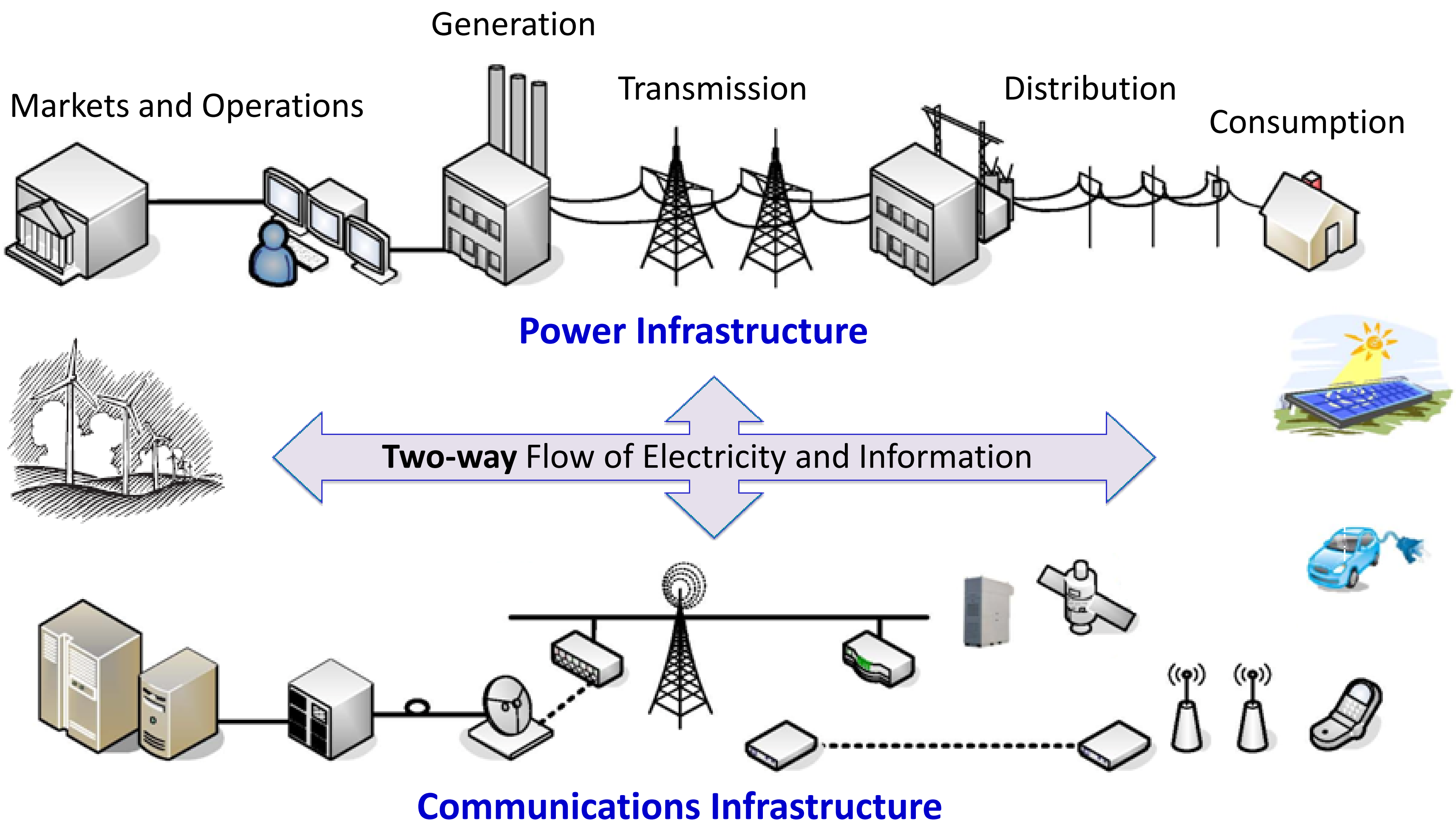
What is Smart Grid?

- Future Smart Grid:



What is Smart Grid?

- Future Smart Grid:



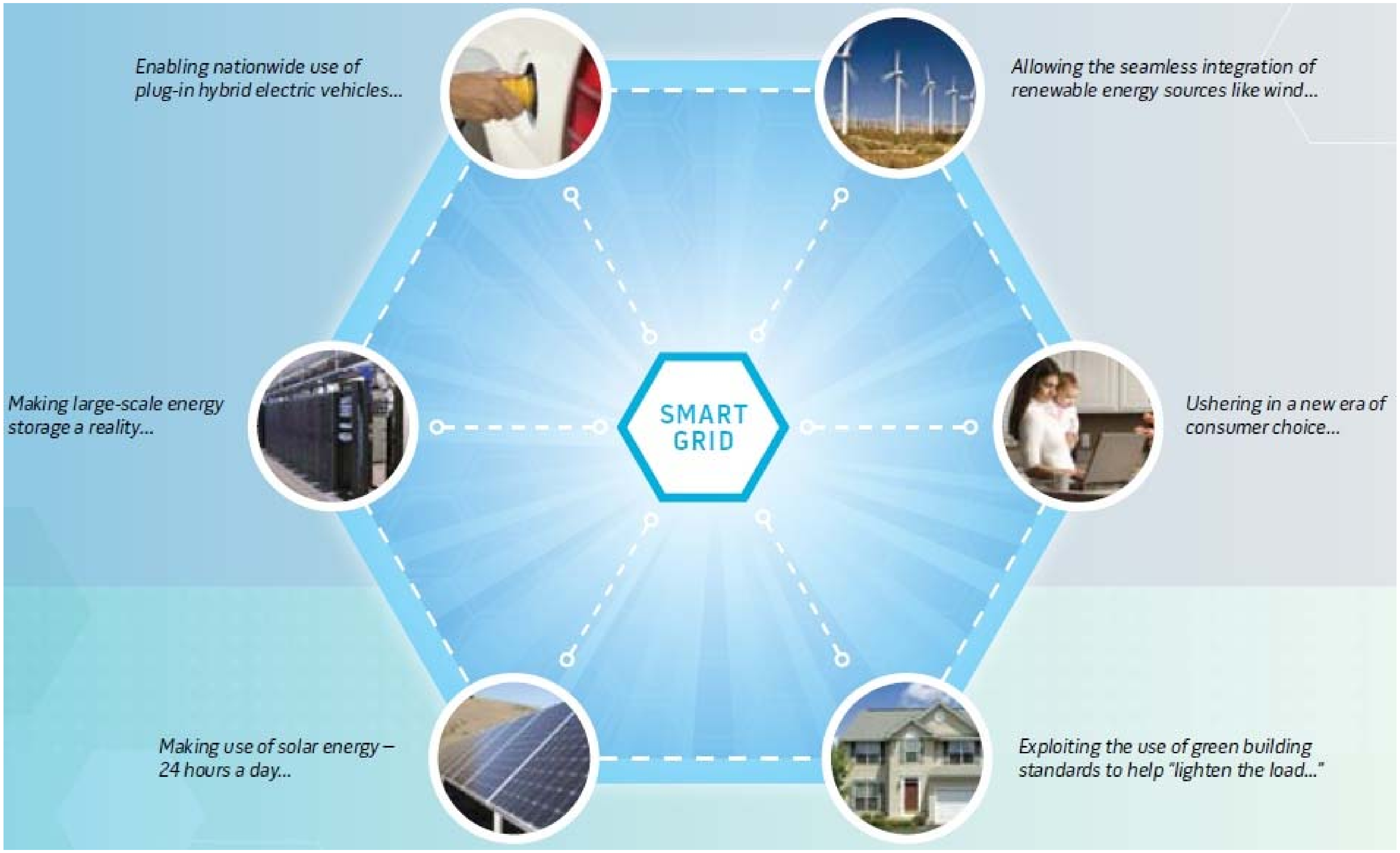
What is Smart Grid?

- According to the U.S. Department of Energy (DoE):

> “Smart grid” generally refers to a class of technologies that people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation. These systems are made possible by two-way digital communications technologies and computer processing that has been used for decades in other industries. They are beginning to be used on electricity networks, from the power plants and wind farms all the way to the consumers of electricity in homes and businesses. They offer many benefits to utilities and consumers -- mostly seen in big improvements in energy efficiency and reliability on the electricity grid and in energy users’ homes and offices.

What is Smart Grid?

- According to the U.S. Department of Energy (DoE):



Anticipated Smart Grid Benefits

- According to the National Inst. of Standards and Technology (NIST):

  - 1. Improving Power Reliability and Quality
    - Better monitoring using sensor networks and communications
    - Better and faster balancing of supply and demand

  - 2. Minimizing the Need to Construct Back-up (Peak Load) Power Plants
    - Better demand side management
    - The use of advanced metering infrastructures

Anticipated Smart Grid Benefits

- According to the National Inst. of Standards and Technology (NIST):

  - 3. Enhancing the capacity and efficiency of existing electric grid
    - Better monitoring using sensor networks and communications
    - Consequently, better control and resource management in real-time

  - 4. Improving Resilience to Disruption and Being Self-Healing
    - Better monitoring using sensor networks and communications
    - Distributed grid management and control

Anticipated Smart Grid Benefits

- According to the National Inst. of Standards and Technology (NIST):

  - 5. Expanding Deployment of Renewable and Distributed Energy Sources

    - Better monitoring using sensor networks and communications
    - Consequently, better control and resource management in real-time
    - Better demand side Management
    - Better renewable energy forecasting models
    - Providing the infrastructure / incentives

Anticipated Smart Grid Benefits

- According to the National Inst. of Standards and Technology (NIST):

  - 6. Automating maintenance and operation
    - Better monitoring using sensor networks and communications
    - Distributed grid management and control

  - 7. Reducing greenhouse gas emissions
    - Supporting / encouraging the use of electric vehicles
    - Renewable power generation with low carbon footprint

Anticipated Smart Grid Benefits

- According to the National Inst. of Standards and Technology (NIST):

  - 8. Reducing oil consumption
    - Supporting / encouraging the use of electric vehicles
    - Renewable power generation with low carbon footprint
    - Better demand side Management (Q: Why?)

  - 9. Enabling transition to plug-in electric vehicles
    - Can also provide new storage opportunities

Anticipated Smart Grid Benefits

- According to the National Inst. of Standards and Technology (NIST):
  - 10. Increasing consumer choice
    - The use of advanced metering infrastructures
    - Home automation
    - Energy smart appliances
    - Better demand side Management

Anticipated Smart Grid Benefits

- Average Cost for 1 Hour of Power Interrupt:

INDUSTRY	AMOUNT
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

Ref: U.S. Department of Energy

- Smart grid is worth investing?

Smart Grid Projects in United States

Ref: www.sgiclearinghouse.org.

AMI represents Advanced Metering Infrastructure (AMI)

IS represents Integrated Systems (IS)

CS represents Customer Systems (CS)

TS represents Transmission Systems (TS)

DS represents Distribution Systems (DS)

RD represents Regional Demonstration (RD)

EM represents Equipment Manufacturing (EM)

SD represents Storage Demonstration (SD)

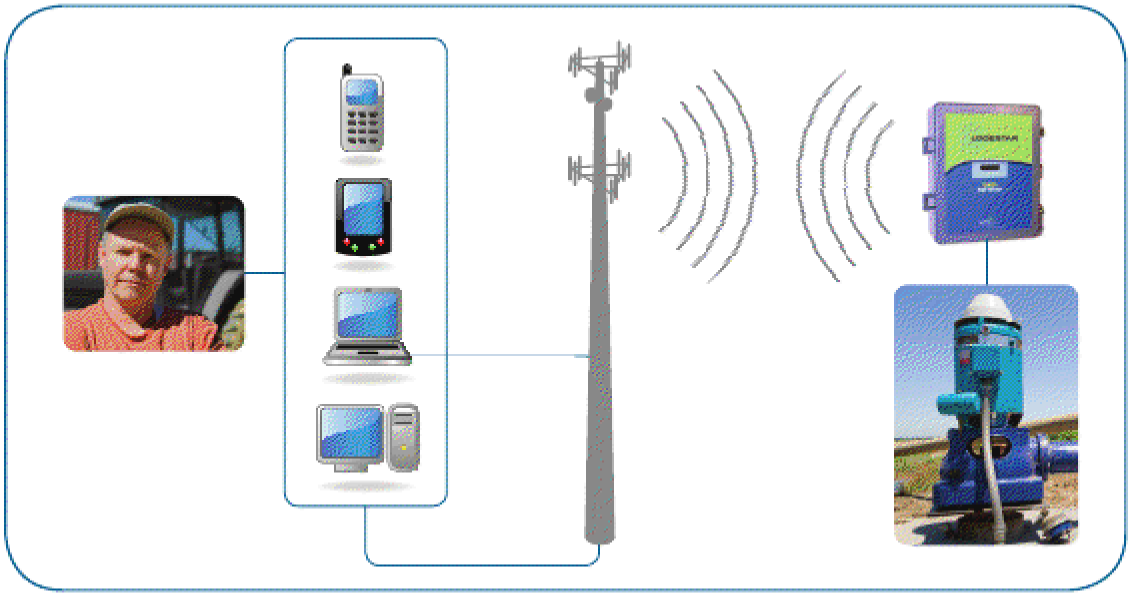
Advanced Metering Infrastructure (AMI) Example

- AMI Project in Lubbock, TX
  - South Plains Electric Cooperative AMI Project
  - Started in 1996
  - To talk back and forth with utilities
  - Report outages and electric usage
  - 34,285 smart meters already connected (75%)
  - Targeting 100% by 2014!

Smart Meter

Customer System (CS) Example

- Peak Energy Agriculture Rewards (PEAR) in Fresno, CA
  - Demand response program for agriculture customers
  - Cell phone / web-to-wireless remote control.



Customer System (CS) Example

- Peak Energy Agriculture Rewards (PEAR) in Fresno, CA
  - Controls:
    - On/off switches
    - Pump pressure and flow
    - Air temperature
    - Soil moisture, etc.

  - Monthly cash payments for "negawatt" in peak demand
  - PEAR is registered demand response "aggregator".

Equipment Manufacturing (EM) Example

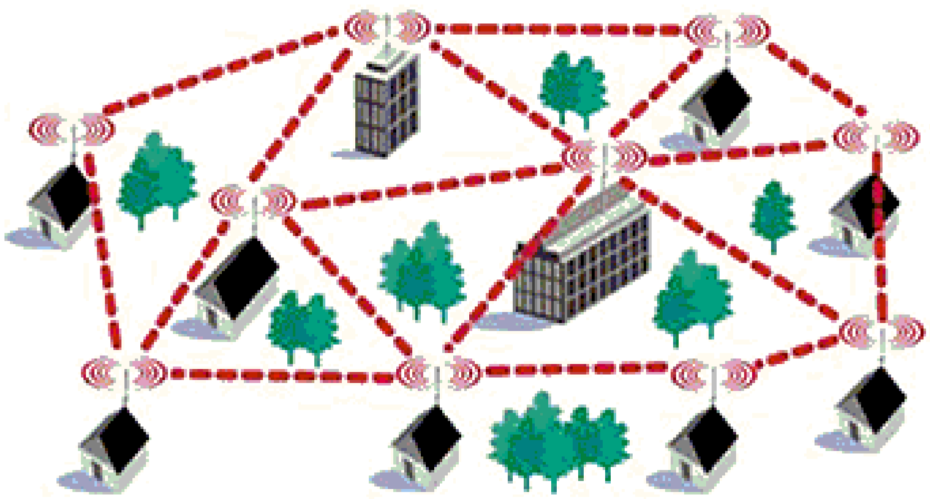
- Whirlpool Corporation Smart Grid Project, Benton Harbor, MI
  - Manufacturing of smart residential
  - Communicating over a home network, Internet, and AMI
  - Will allow consumers to defer or schedule their energy use
    - Clothes dryers, dishwashers, and refrigerators
    - Has user-interface to program appliances
  - Smart Dryer: http://www.youtube.com/watch?v=fISKjaFRh3Q

Integrated System (IS) Example

- Golden Spread Electric Cooperative Project in Amarilo, TX
  - SCADA Communication for Better Reliability & Outage Management
    - Both wireless and power line carrier communications systems
  - Automated Distribution Circuit Switches
  - Automated Capacitors
  - Automated Regulators
  - Circuit Monitors/Indicators
  - Smart Meters, Programmable Communicating Thermostats, DLC

Distribution System (DS) Example

- SGIG Distribution Automation Project, Atlantic City, NJ
  - Wireless Mesh Networking with Fiber Optic Connectivity
    - – Access Points
    - – Mesh Repeaters
  - Automation
    - – Monitoring
    - – Control / Switching



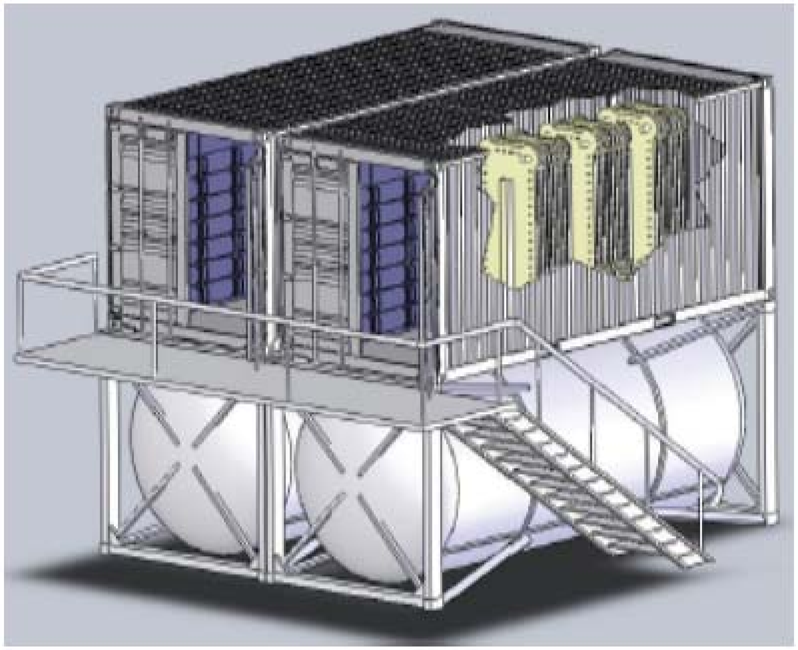
Wireless Mesh Network

Transmission Systems (TS) Example

- Midwest Energy Inc. Smart Grid Project, Hays, KS
  - Nine Relay-based Phasor Measurement Units (PMUs)
  - Synchrophasor Communications Network
  - Advanced transmission applications for synchrophasors:
    - Angle and frequency monitoring
    - Post-mortem analysis (disturbances and system failures)
    - Voltage and voltage stability monitoring
    - Improved state estimation
    - Steady-state benchmarking

Storage Demonstration (SD) Example

- Ktech Corp: Battery for Renewable Energy Integration
  - California's Central Valley
  - Batteries: 250 kW, 1 MWh
  - 180 kW Photovoltaic Farm
  - Store the energy generated
  - Dispatch power to:
    - Run an irrigation pump
    - Inject energy back into the grid during peak times



Major Government / Local Agencies Involved

- Energy Independence and Security Act of 2007

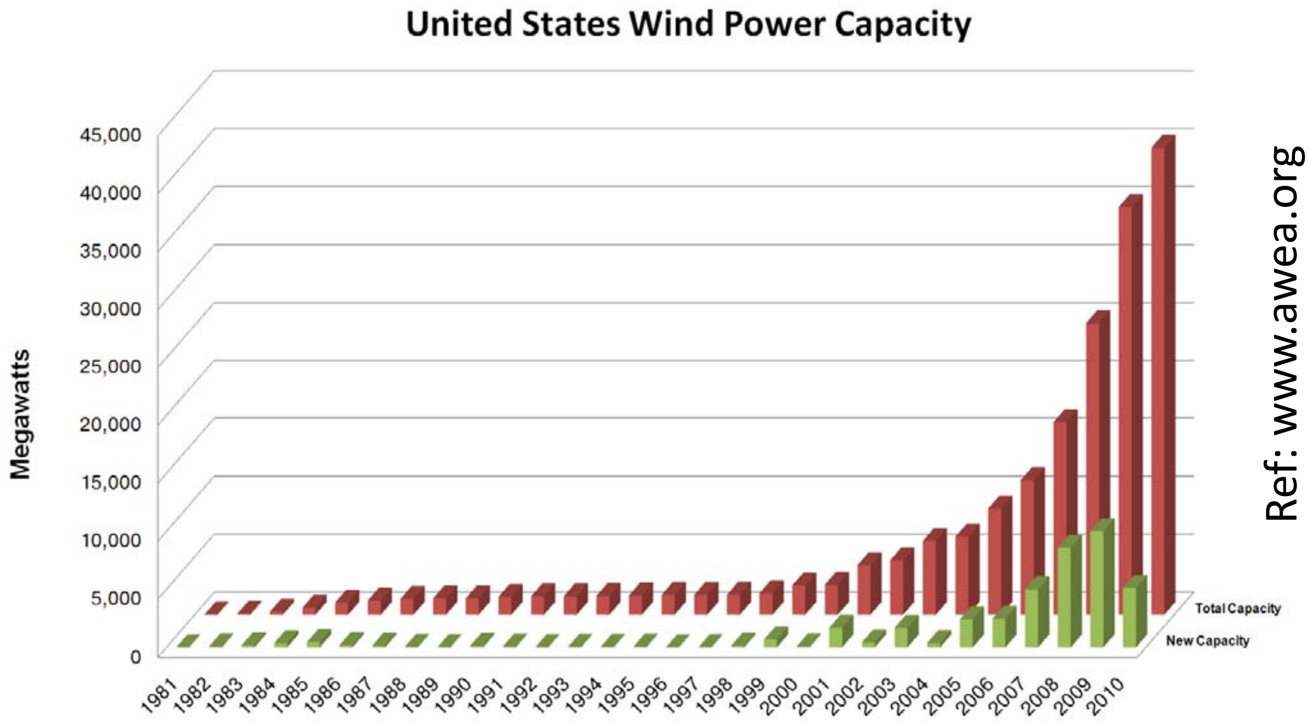
- American Recovery and Reinvestment Act of 2009

Smart Grid Priority Areas

Eight Priority Areas to Build a Smart Grid (Identified by NIST)
1. Demand Response and Consumer Energy Efficiency
2. Wide-Area Situational Awareness
3. Energy Storage
4. Electric Transportation
5. Advanced Metering Infrastructure
6. Distribution Grid Management
7. Cyber Security
8. Network Communications

Some Ambitious Targets

- U.S. DoE Wind Power Target: 20% Wind Power by 2030!



Ref: www.awea.org

Total U.S. Wind Power Capacity in 2011: 43,461 MW

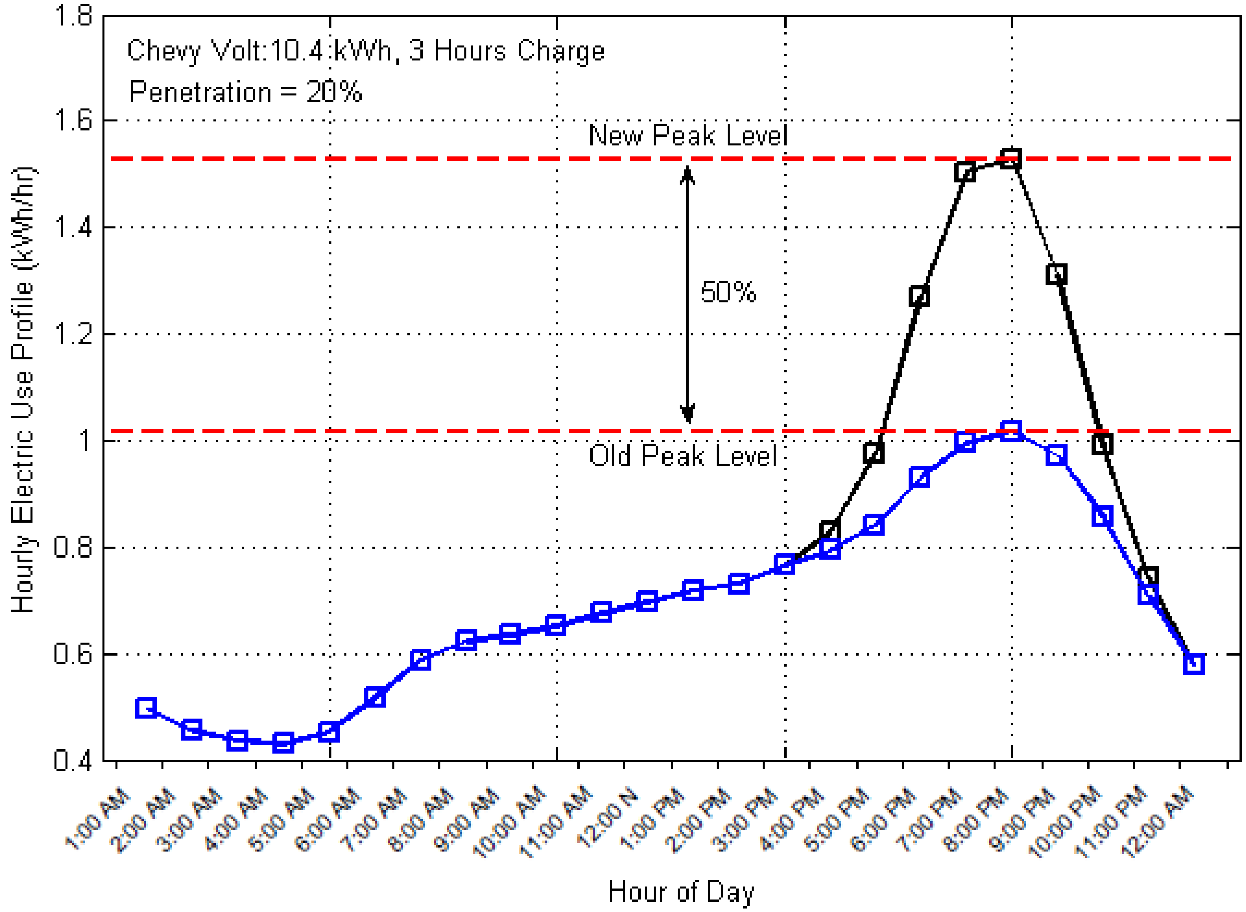
Total Peak Load in Texas on January 12, 2012: 44,118 MW!

Some Ambitious Targets

- Plug-in Electric Vehicles Target: 1 Million by 2015!
- From Dec 2010 to Dec 2011:
  - Total of 18,000 plug-in electric cars are sold in the U.S.
    - Rank 1: Nissan Leaf (9,693 units)
    - Rank 2: Chevrolet Volt (7,997 units)

Some Ambitious Targets

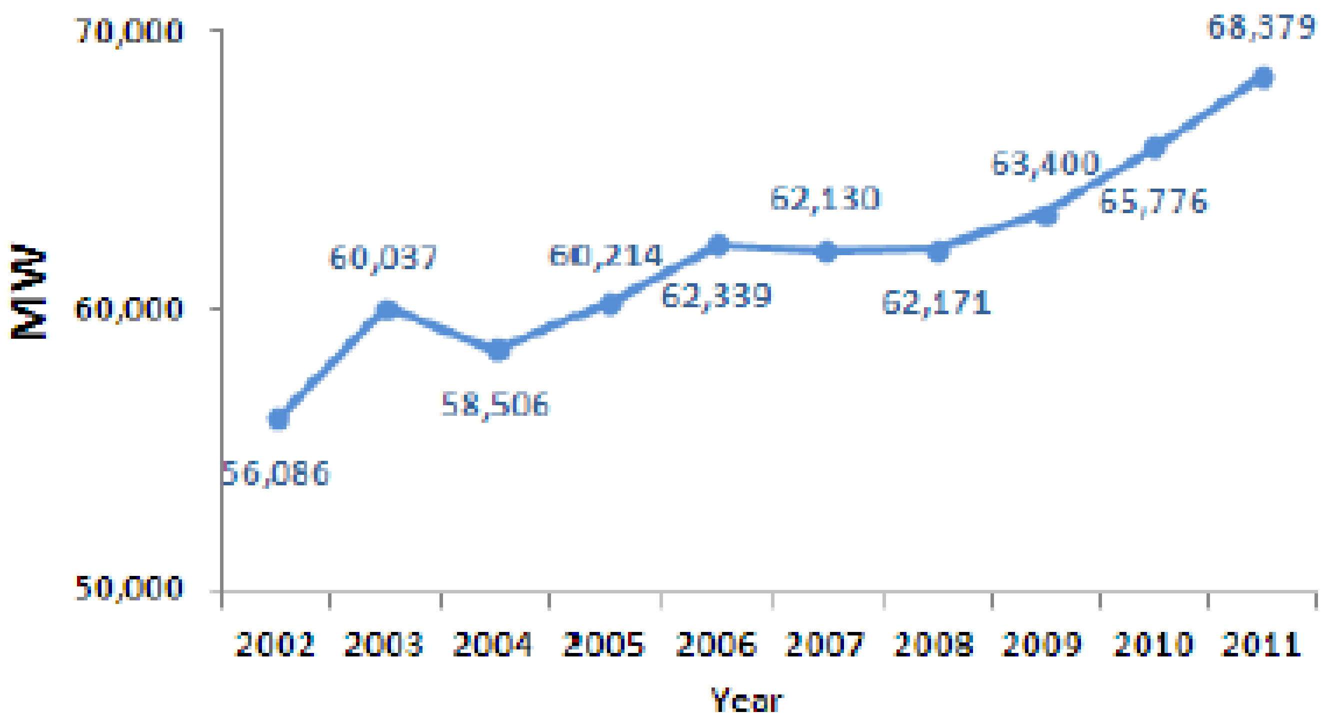
- DoE Demand Response Target: Shaving 20% of Peak Load



Residential Load Profile (Cal. Edison)

Some Ambitious Targets

- Historical Peak Load Trend in Texas:



Historical Peak Load (Texas ERCOT)

[Peak load is historically increasing, PHEVs are coming, …]

Smart Grid Standards

- IEEE is a key player in Smart Grid Standardization

- IEEE has over 100 Smart Grid-related approved standards:
  - http://smartgrid.ieee.org/standards/approved-ieee-smart-grid-standards

- IEEE also has several Smart Grid-related pending standards:
  - http://smartgrid.ieee.org/standards/proposed-standards-related-to-smart-grid

Smart Grid Standards / Examples

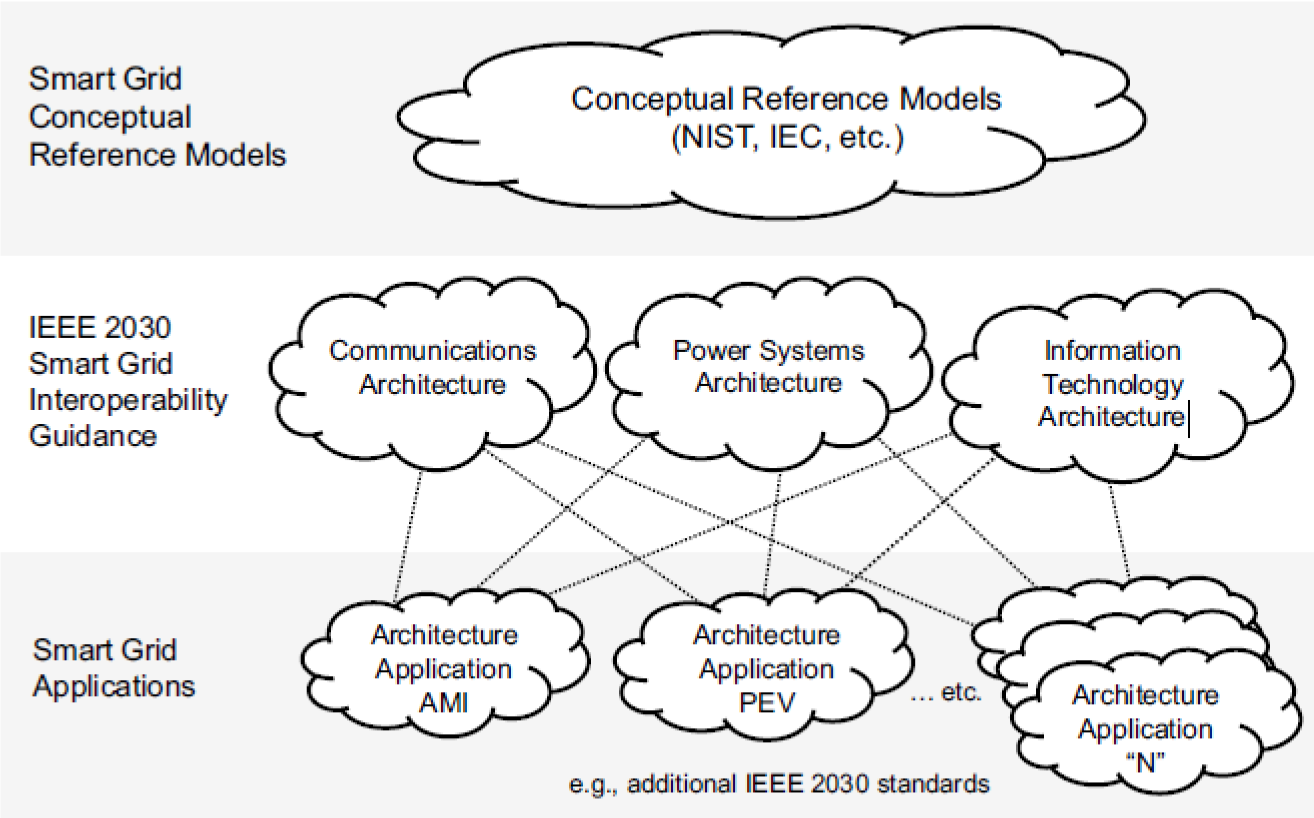
1. IEEE Guide for Smart Grid Interoperability (IEEE P2030)

Interoperability is the capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information securely and effectively.

- Provides reference models for:
  - Smart grid architecture
  - Smart grid information exchange

Smart Grid Standards / Examples

IEEE 2030 Smart Grid Interoperability Architecture:



Ongoing Projects: IEEE 2030.1 (PEV), 2030.2 (Storage), 2030.3

Smart Grid Standards / Examples

IEEE 2030 Smart Grid Interoperability Reference Model (SGIRM):

<table>
<tr><th>Data characteristic</th><th colspan="6">Classification/Value range</th></tr>
<tr><td>Data use category</td><td colspan="6">To be determined by the user of the table based on the intended use of the data (i.e., control data, protection data, and/or monitoring data)</td></tr>
<tr><td>Reach</td><td colspan="3">meters (feet)</td><td colspan="3">kilometers (miles)</td></tr>
<tr><td>Information transfer time</td><td><3 ms</td><td colspan="2">Between 3 ms and 10 s</td><td colspan="2">Between 10 s and minutes</td><td>hours</td></tr>
<tr><td>Data occurrence interval</td><td>milliseconds</td><td colspan="2">seconds</td><td colspan="2">minutes</td><td>hours</td></tr>
<tr><td>Method of broadcast</td><td>Unicast</td><td colspan="2">Multicast</td><td colspan="2">Broadcast</td><td>All</td></tr>
<tr><td>Priority</td><td colspan="2">Low</td><td colspan="2">Medium</td><td colspan="2">High</td></tr>
<tr><td>Latency</td><td>Low-low (<3 ms)</td><td colspan="2">Low (<16 ms)</td><td colspan="2">Medium (<160 ms)</td><td>High (≥160 ms)</td></tr>
<tr><td>Synchronicity</td><td colspan="3">Yes</td><td colspan="3">No</td></tr>
<tr><td>Information reliability</td><td colspan="2">Informative</td><td colspan="2">Important</td><td colspan="2">Critical</td></tr>
<tr><td>Availability (information reliability)</td><td colspan="2">Low (limited impact)</td><td colspan="2">Medium (serious impact)</td><td colspan="2">High (severe or catastrophic impact)</td></tr>
<tr><td>Level of assurance</td><td colspan="2">Low</td><td colspan="2">Medium</td><td colspan="2">High</td></tr>
<tr><td>HEMP, IEMI</td><td colspan="3">Hardened, yes</td><td colspan="3">Hardened, no</td></tr>
<tr><td>Data volume</td><td>bytes</td><td colspan="2">kilobytes</td><td colspan="2">megabytes</td><td>gigabytes</td></tr>
<tr><td>Security</td><td colspan="2">Low (limited impact)</td><td colspan="2">Medium (serious impact)</td><td colspan="2">High (severe or catastrophic impact)</td></tr>
<tr><td>Confidentiality</td><td colspan="2">Low (limited impact)</td><td colspan="2">Medium (serious impact)</td><td colspan="2">High (severe or catastrophic impact)</td></tr>
<tr><td>Integrity</td><td colspan="2">Low (limited impact)</td><td colspan="2">Medium (serious impact)</td><td colspan="2">High (severe or catastrophic impact)</td></tr>
<tr><td>Availability (security)</td><td colspan="2">Low (limited impact)</td><td colspan="2">Medium (serious impact)</td><td colspan="2">High (severe or catastrophic impact)</td></tr>
</table>

Provides guidelines for information exchange aspects…

Smart Grid Standards / Examples

2. IEEE Standard for Synchrophasor Data Transfer for Power Systems [PC37.118.2]

- CRC (Cyclic Redundancy Check) Error Detection.
- Synchrophasor measurements shall be tagged with the UTC
  - Second-of-century count (SoC)
  - Fraction-of-second count (FracSec)
  - Time Quality Flag

Smart Grid Standards / Examples

- Second-of-century count (SoC)
  - Four bytes / 32 bits
  - Unsigned integer
  - Counts seconds from UTC midnight (00:00:00) of January 1, 1970
  - Will roll over to zero in 2106 (Q: Why?)
- Three bytes for FracSec and one byte for Time Quality Flag.

Smart Grid Standards / Examples

- PMU Reporting Rates

  - Required Rate:

System frequency	50 Hz			60 Hz					
Reporting rates (F_s—frames per second)	10	25	50	10	12	15	20	30	60

  - Also Encouraged:

    – 100 frames / sec and 120 frames / sec

    – 10 frames / sec and 1 frame / sec

[We will see more details under Topic 6 – Wide Area Measurement]

AC or DC?

- Many energy-consuming devices operate internally on DC power.
  - Computers
  - Televisions
  - Cell Phones (Most portable devices)
- Currently, they need to use AC-DC adapters.
- AC-DC conversion for these devices waste:
  - Up to 20% total power consumed

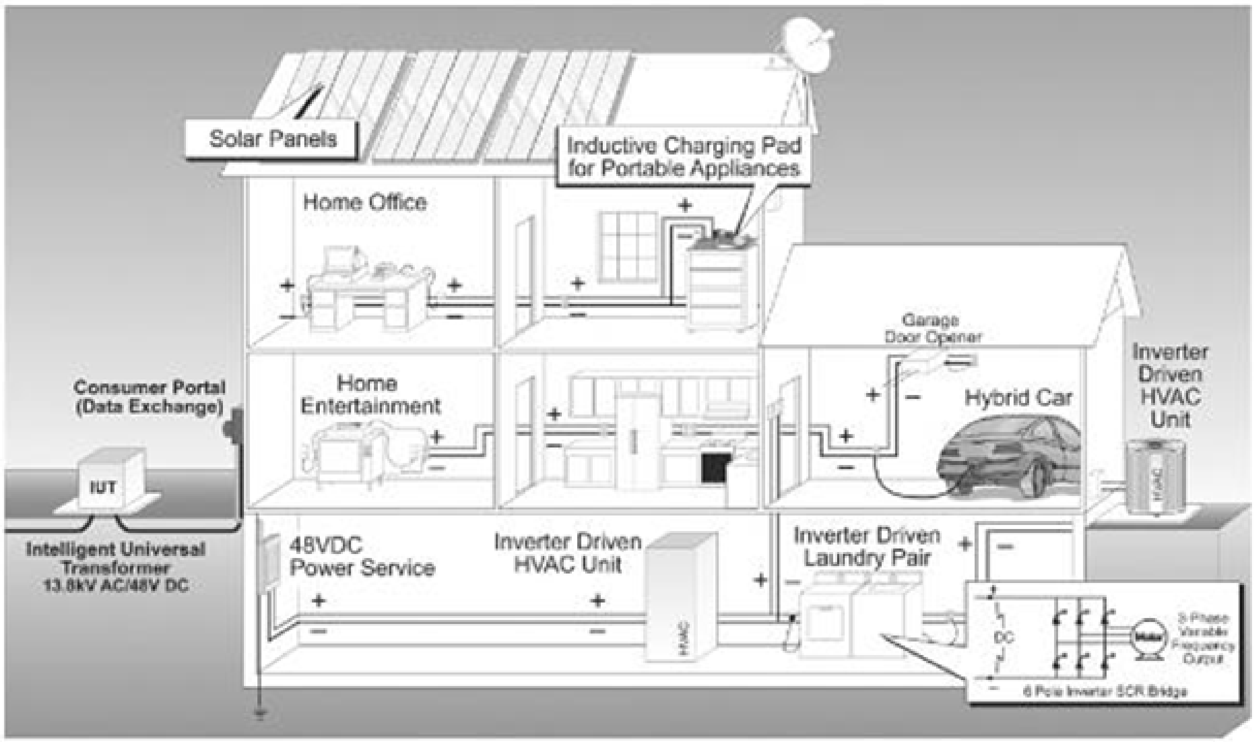
AC or DC?

- Some renewable sources essentially generate DC power
  - Photovoltaic (PV) Arrays
- Most storage devices operate internally on DC power
  - Most batteries
  - Electric Vehicles / PHEVs (Distributed Storage)

Q: Why not operate smart grid (or part of it) in DC power?!

AC or DC?

- DC power system for tomorrow's home:



Ref: C. W. Gellings, www.galvapower.org

AC or DC?

- Some suggested advantages of a DC power delivery system:
  - DC distribution eliminates harmonics
  - Grounding is simplified
  - DC distribution eliminates power factor concerns
  - Lower maintenance cost and greater reliability

Moving towards a DC power system has its own fans!

References

- Department of Energy, “The Smart Grid: An Introduction”, at http://energy.gov/oe/downloads/smart-grid-introduction.

- C. W. Gellings, *The Smart Grid: Enabling Energy Efficiency and Demand Response*, CRC Press, Aug, 2009.

- A. Carvallo, *The Advanced Smart Grid: Edge Power Driving Sustainability*, Artech House, June, 2011.

- X. Fang, S. Misra, G. Xue, and D. Yang, "Smart Grid - The New And Improved Power Grid: A Survey"; accepted for publication in *IEEE Communications Surveys and Tutorials*, 2012. Available at http://optimization.asu.edu/~xue/papers/SmartGridSurvey.pdf