Introduction to Smart Grid

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NSF SFS Project Team on "Integrated Learning Environment for Smart Grid Security"

Organization of the Slides

- Objective of National Power Grid Modernization
- Architecture of Smart Grid
- What is Smart Grid and What is not
- Examples of Deployment
- Benefits of Smart Grids
- Example Scenarios
- Two Active Research Fields
  - Micro-grid
  - Electricity Market
- Conclusion

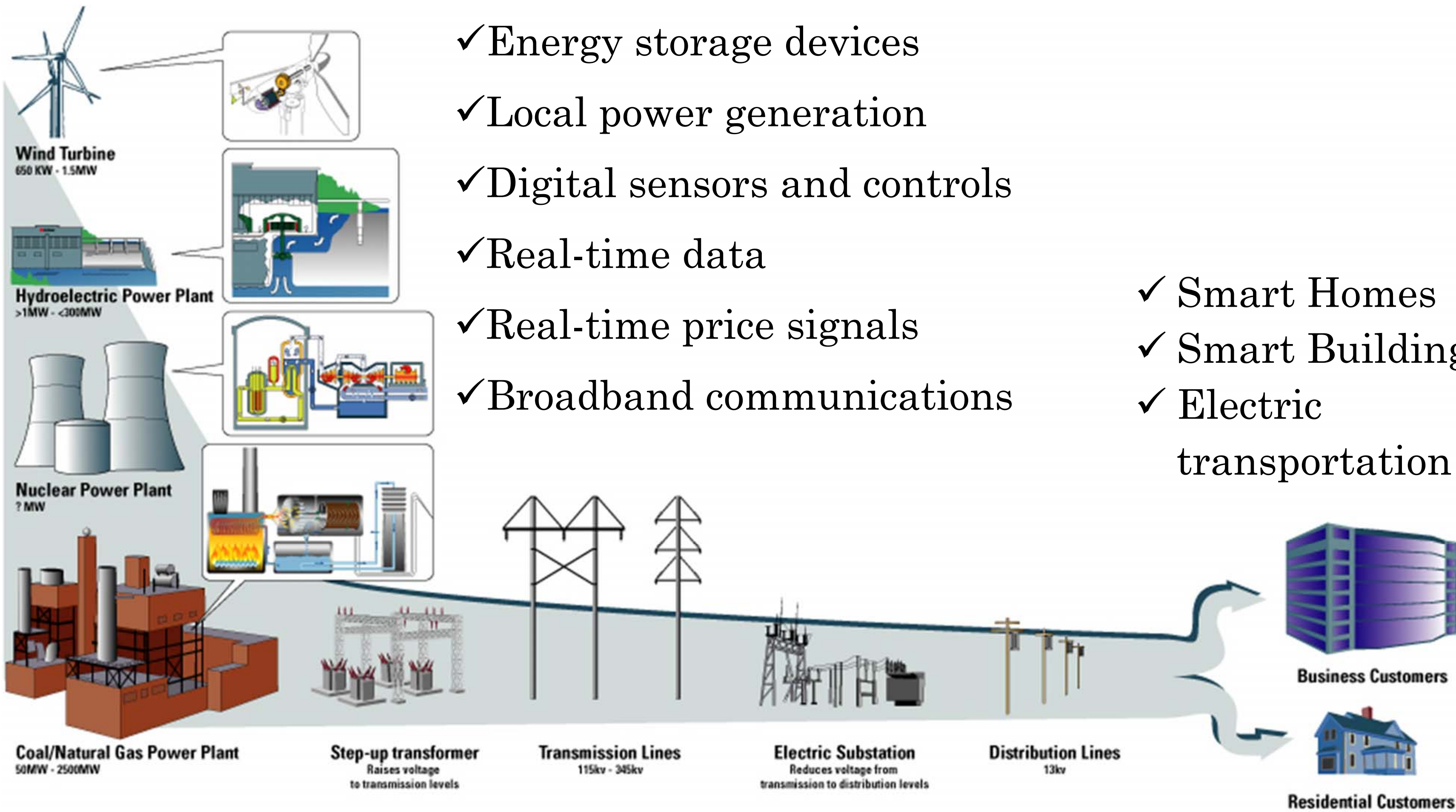
US POWER GRID TODAY

- Over 5,000 power plants, over 200,000 miles of high-voltage transmission, and over 5.5 million miles of distribution lines: one of the most complex systems in the world;
- Evolved very little over past 50 years:
  - Old (the average age of power plants is 35 years)
  - Dirty (more than half of our electricity is generated from coal)
  - Inefficient (the delivered efficiency of electricity is only 35%)
  - Vulnerable (the 2003 blackout in the Northeast affected 55M people for up to two days)
- the annual cost to U.S. businesses of power outages is greater than $100 Billion

PRIMARY OBJECTIVES OF SMART GRIDS

- National integration;
- Self healing and adaptive: improve distribution and transmission system operation;
- Allow customers freedom to purchase power based on dynamic pricing;
- Improved quality of power: less wastage;
- Integration of large variety of generation options;

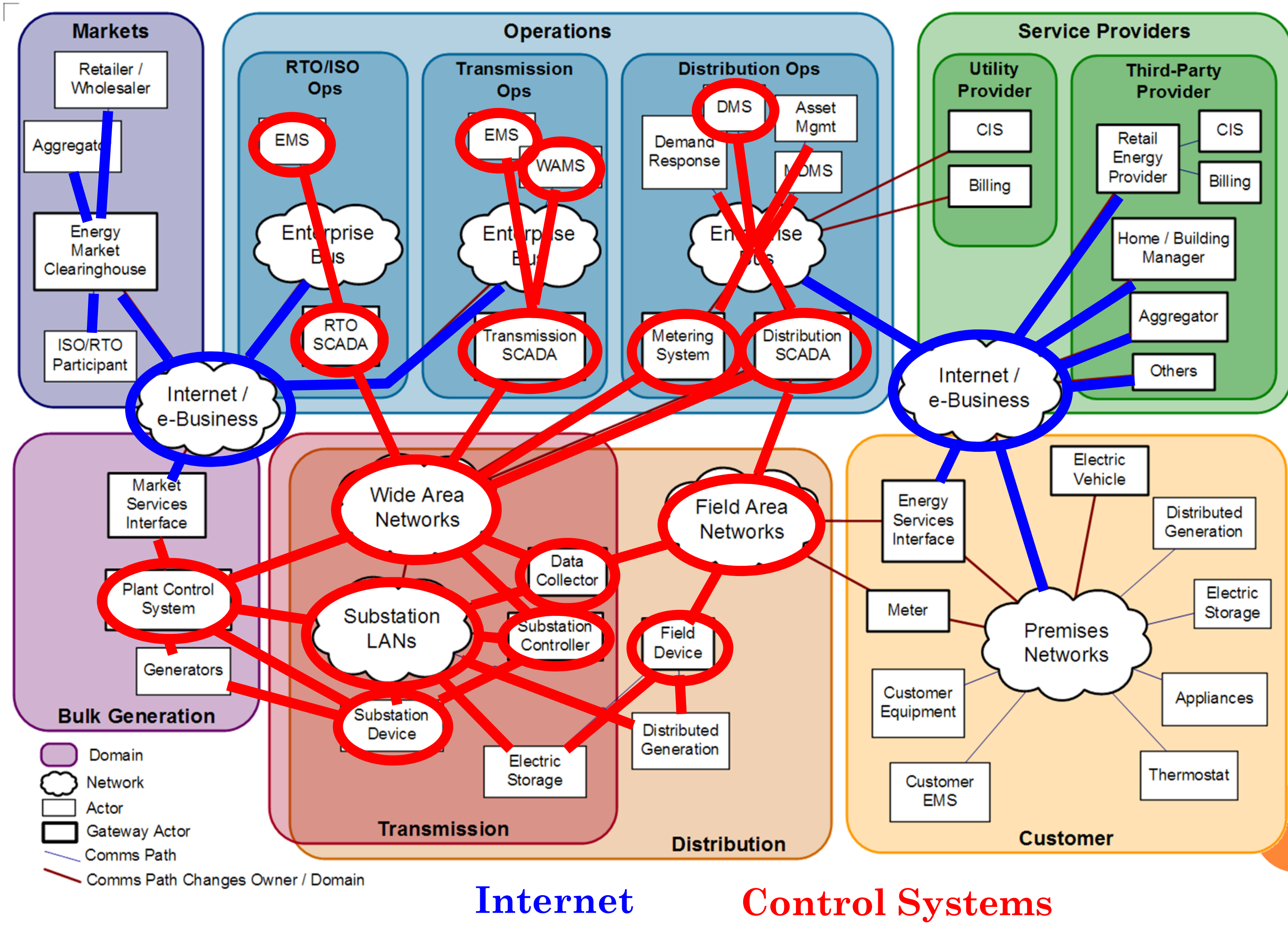
Smart Grid Architecture



- ✓Energy storage devices
- ✓Local power generation
- ✓Digital sensors and controls
- ✓Real-time data
- ✓Real-time price signals
- ✓Broadband communications

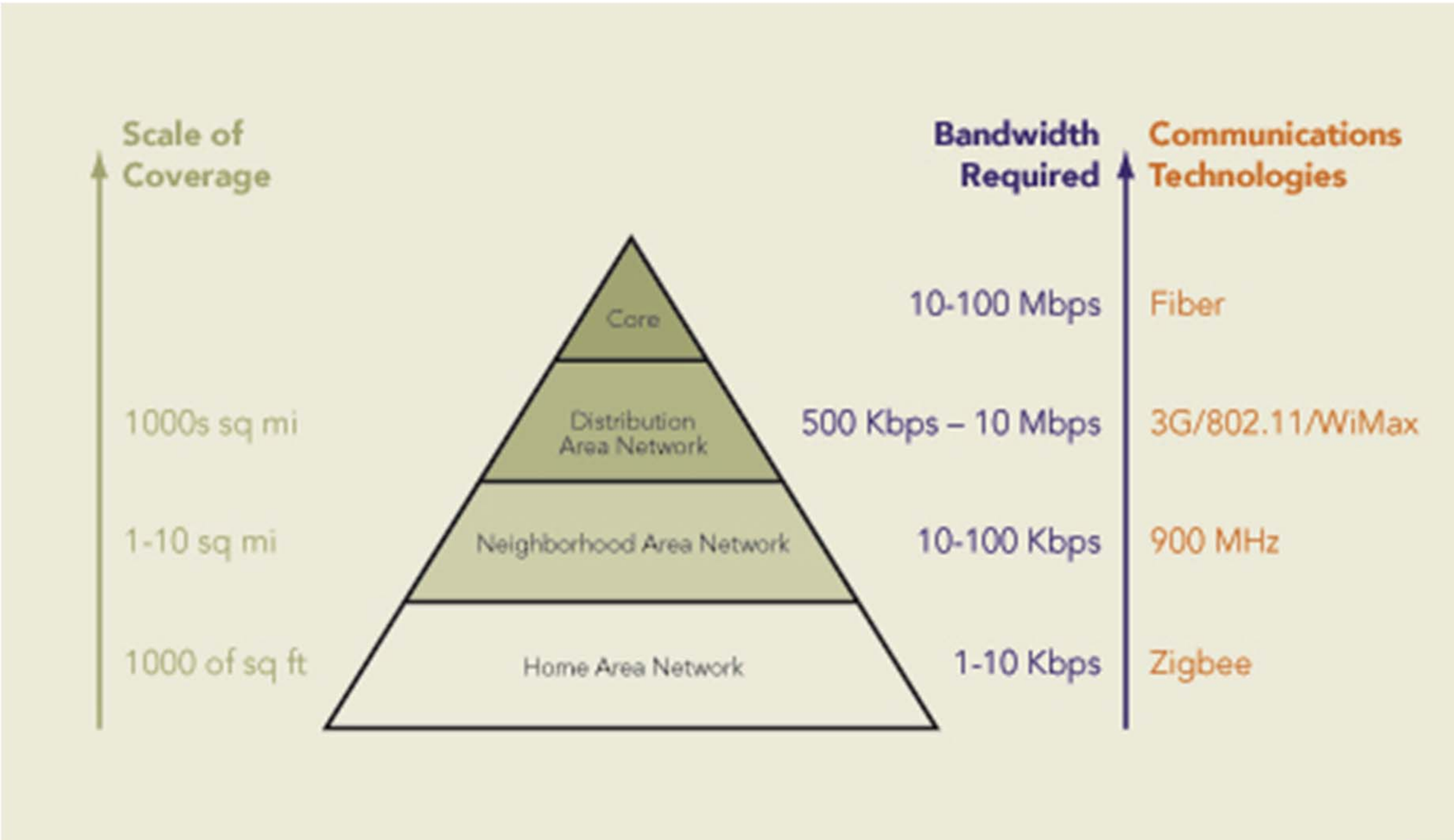
- ✓ Smart Homes
- ✓ Smart Buildings
- ✓ Electric transportation

POWER GRID COMM. & CONTROL: A CLOSE VIEW



borrowed from NIST Smart Grid Twiki

Tiered view of Smart Grid communications



What is Smart Grid

- According to EPRI, Smart Grid is "a modernization of the electricity delivery system so that it monitors, protects, and automatically optimizes the operation of its interconnected elements";
- According to the Federal Energy Regulatory Commission, Smart Grid is "a power system architecture that permits two-way communication between the grid and essentially all devices that connect to it, ultimately all the way down to consumer appliances";

What is not Smart Grid

- Charge you $600 and install a new electric meter at your house only; or
- Use your smart phone to hack and control your neighbor's AC to make her room really hot; or
- Bring the power companies' profit to new record high;

Regulation of Smart Grid

- Agencies:
  - Smart Grid Advisory Council;
  - Federal Smart Grid Task Force;
- Funding Programs:
  - Smart Grid Investment Program (SGIP): 99 SGIP projects, worth a total of $8 Billion;
  - Smart Grid Demonstration Program (SGDP): 32 SGDP projects, worth $1.6 Billion;
  - Will install 60—65 million smart meters by 2015 (50% coverage);

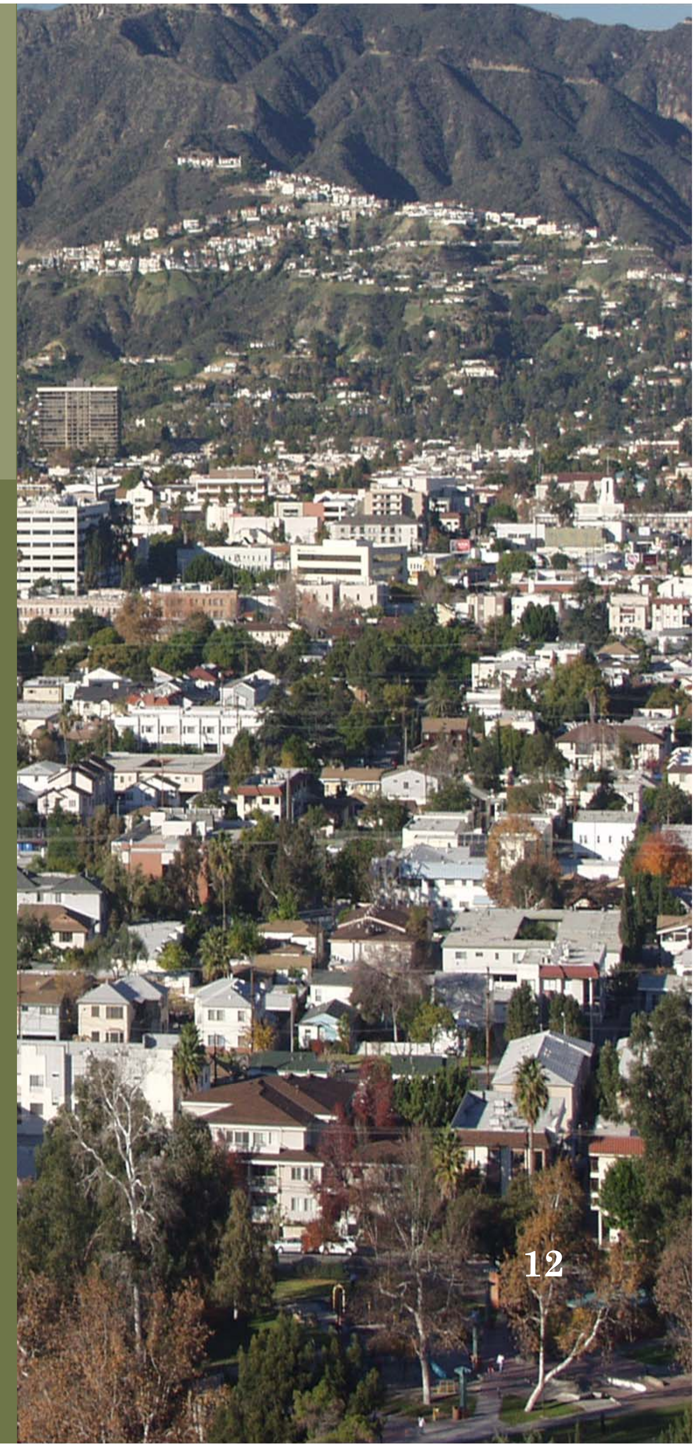
Examples of Deployment

- Glendale, California: over 33,744 water and 85,358 electric customers;
- Abu Dhabi in UAE: 3.3 million annual tourist visits and 251,000 residential units;

Glendale Water and Power

Nation's First ARRA Smart Grid Grant Recipient

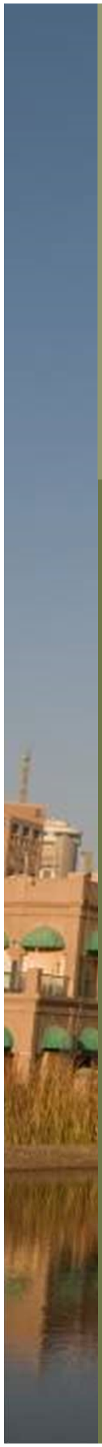
- ARRA Smart Grid award - $20M; total project $51M
- Phase 1: smart meters - 85,000 power and 33,400 water
- Wireless broadband network aggregates communications for utility applications
- Additional smart grid applications: distribution automation, thermal energy storage, demand response
- Other city departments plan to leverage network



United Arab Emirates

Efficient Management of Scarce Resources Emirate-wide

- Wireless mesh network used to read 1.5 million power and water meters in urban, suburban and rural areas
- Smart grid applications include AMI, real-time SCADA substation control, distribution automation, street light control, broadband connectivity for mobile workers, substation video security
- Upon completion the network will cover 5,000+ square kilometers



Anticipated Smart Grid Benefits

- A modernized national electrical grid:
  - Improves power reliability and quality;
  - Optimizes facility utilization and averts construction of backup (peak load) power plants;
  - Enhances capacity and efficiency of existing electric power networks;
  - Improves resilience to disruption;
  - Enables predictive maintenance and “self-healing” responses to system disturbances;
  - Facilitates expanded deployment of renewable energy sources;
  - Accommodates distributed power sources;

Anticipated Smart Grid Benefits (cont.)

- Reduces greenhouse gas emissions by enabling electric vehicles and new power sources;
- Presents opportunities to improve grid security;
- Increases consumer choice;
- Enables new products, services, and markets and consumer access to them;

- Example Scenarios
  - Substation
  - Outage Management
  - End Consumers
  - Communication Networks

Smart Substation

Scenario:

Digital intelligence gives substation operators remote control of facilities.

- Allows faster adjustments to conditions
- Prevents blackouts, makes for faster recovery
- More flexibility to re-route power
- Monitors help keep facilities and sites secure

Smart Outage Management

<u>Scenario:</u>

A customer's power goes out at their home; but they don't need to call the utility. It's already located the cause of the outage.

- Sensors & monitors embedded throughout the grid detect abnormalities/disruptions
- Real-time data leads to rapid diagnosis and correction
- The utility company is able to send the right crew, with the right tools, to the right location to fix it
- Faster restoration time and fewer outage minutes

SMART HOUSE

Scenario:

Home appliances contain onboard intelligence that receives signals from energy company and can reduce demand when the grid is under stress.

- Consumers automatically pre-program appliances to turn on when prices are lower
- Creates options for managing bills and energy consumption habits

MICROGRIDS AND THE GRID INTERACTION

- Microgrids could have a grid interconnection to
  - Improve system economics
  - Improve operation
  - Improve availability
- With a suitable planning, grid planning can benefit from having microgrids by
  - Reducing conductor's size
  - Improving availability
  - Improving stability
- Tools, strategies and techniques for an effective integration of a microgrid into the main grid:
  - Net metering – bi-directional power flow.
  - Peak shaving
  - Advanced communications and controls
  - Demand response

MICROGRIDS AND THE GRID INTERACTION

- Potential issues with microgrids integration into the main grid:
  - Infrastructure long term planning / economics:
    - Lack of coordination in planning the grid and microgrids;
    - Microgrids may "pop-up" afterwards "without notice";
    - Grid's planning links economic and technical aspects;
  - Stability: microgrids are variable loads with positive and negative impedance (they can act to the grid as generators)

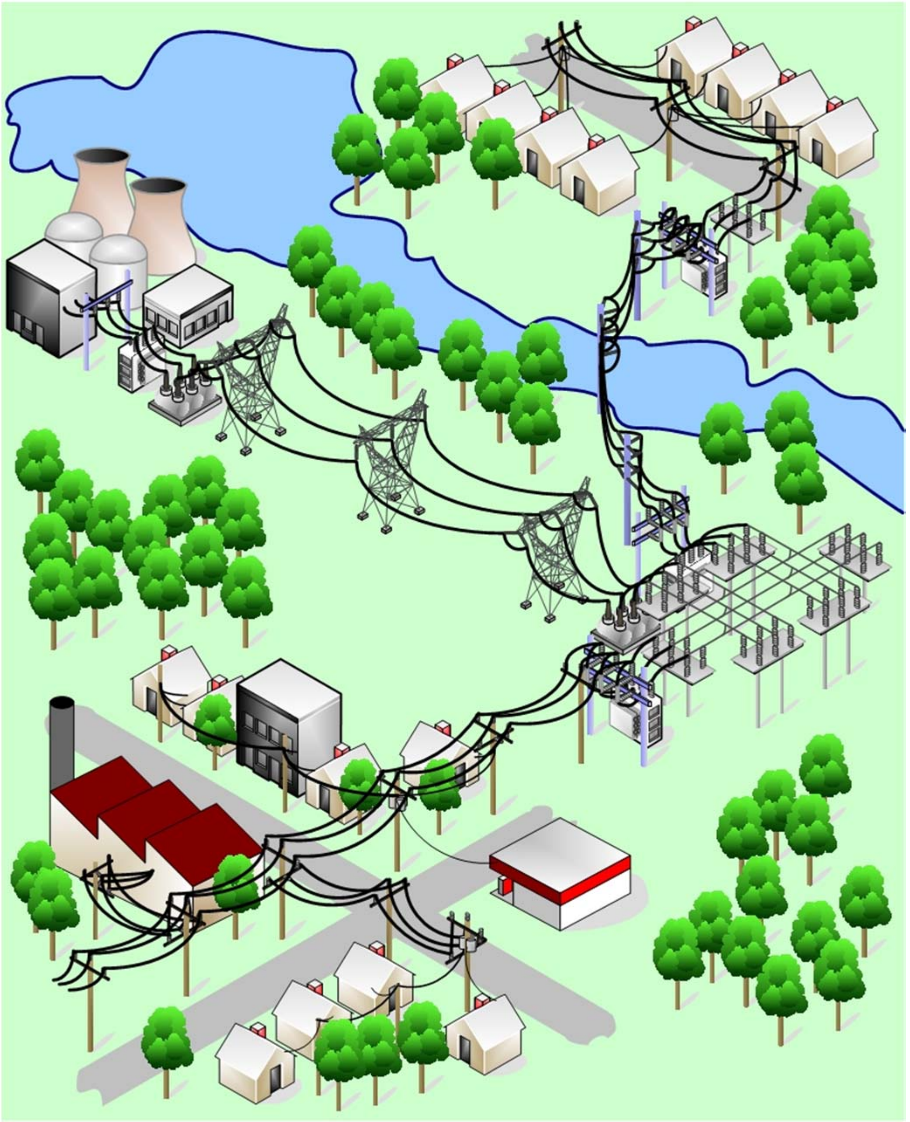
MICROGRIDS AND THE GRID INTERACTION

- More potential issues with microgrids integration into the main grid:
  - Safety: When there is a fault in the grid, power from the microgrid into the grid should be interrupted (islanding)
  - Availability: Microgrids can trigger protections (directional relays) upstream in the grid and interrupt service to other loads
- Key issue: microgrids are supposed to be <u>independently</u> controlled cells within the main grid.
  - How much independence microgrids should have?
    - Does independence apply also to planning?
    - How much interaction/communications should be between the grid and the microgrid?

MICROGRIDS AND THE GRID INTERACTION

- Example of microgrid development. Initial condition.

  - Equipment and financial planning is done with all the load in the figure in mind.

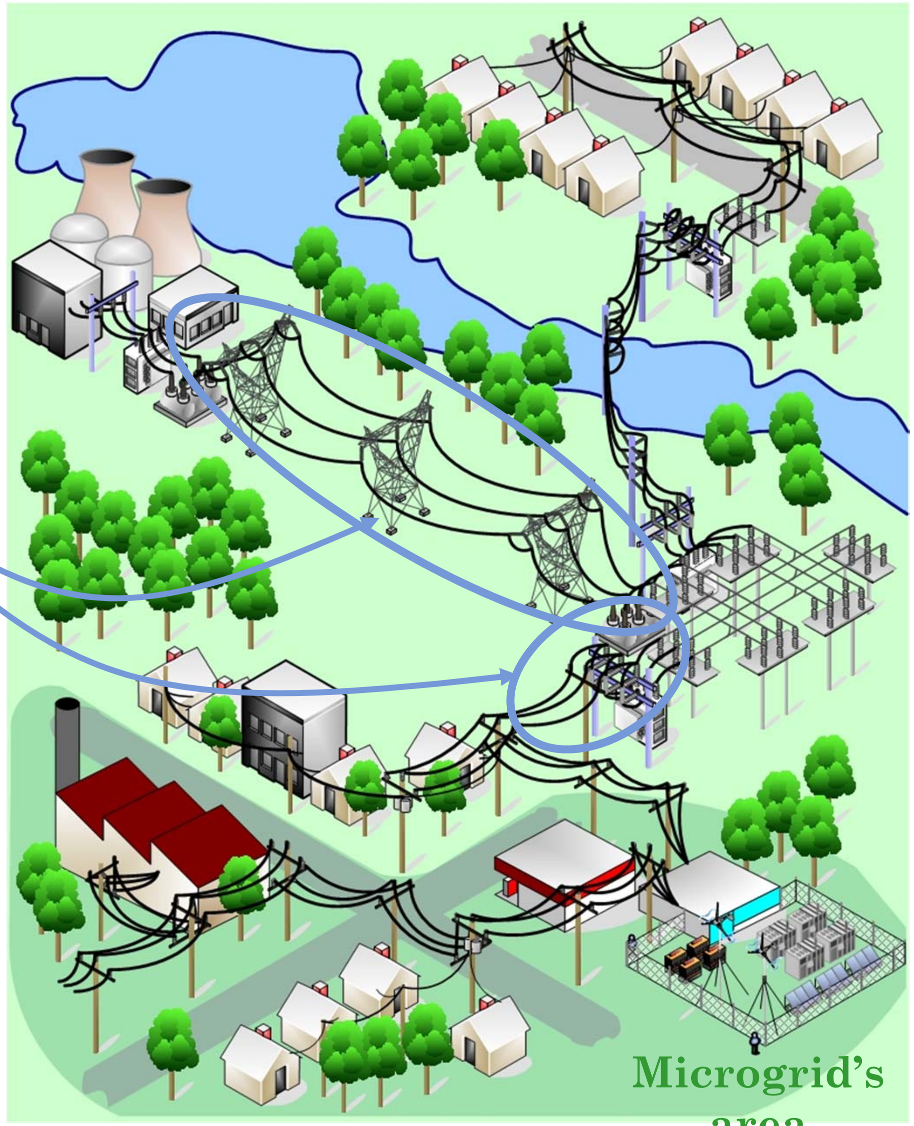


Microgrids and the grid interaction

- A microgrid is installed few years later.

Transformers and conductors can now be oversized

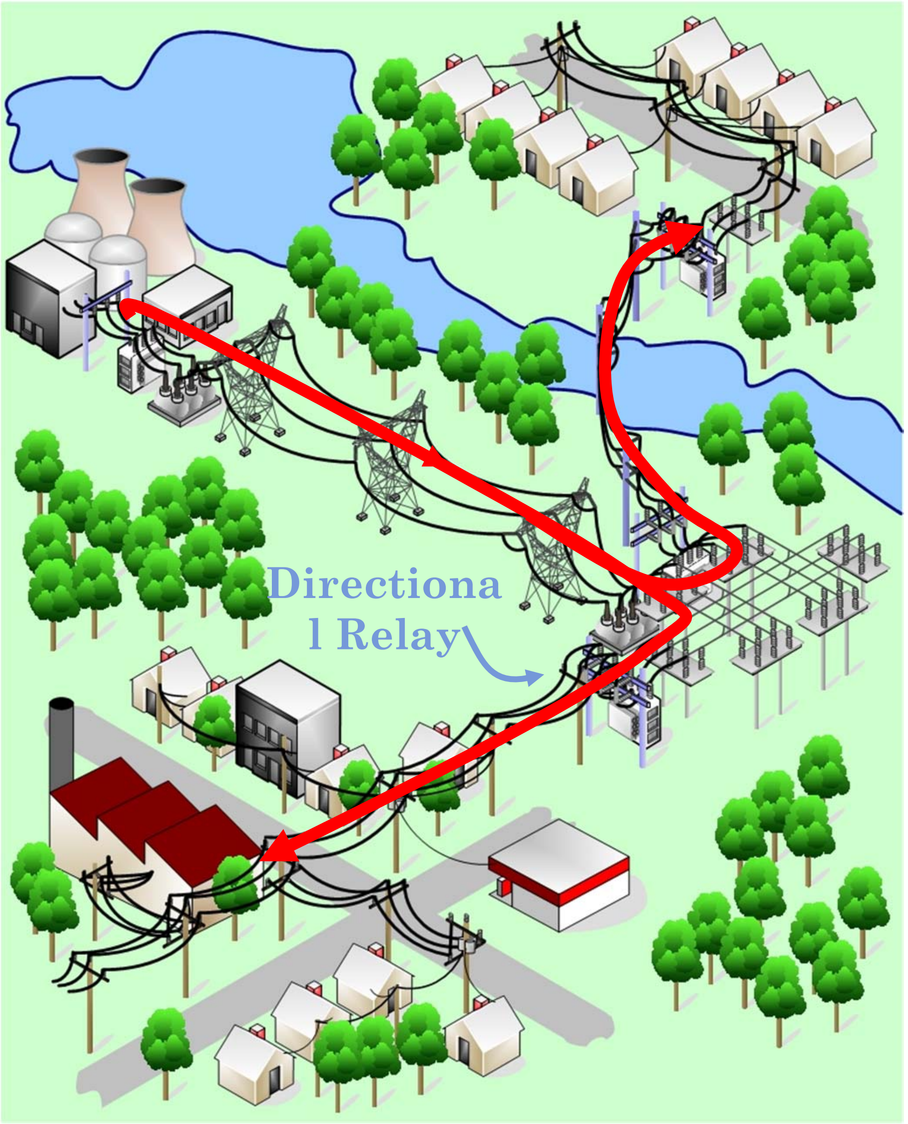
(remember this aspect for PEV and PHEV integration)



Microgrid's area

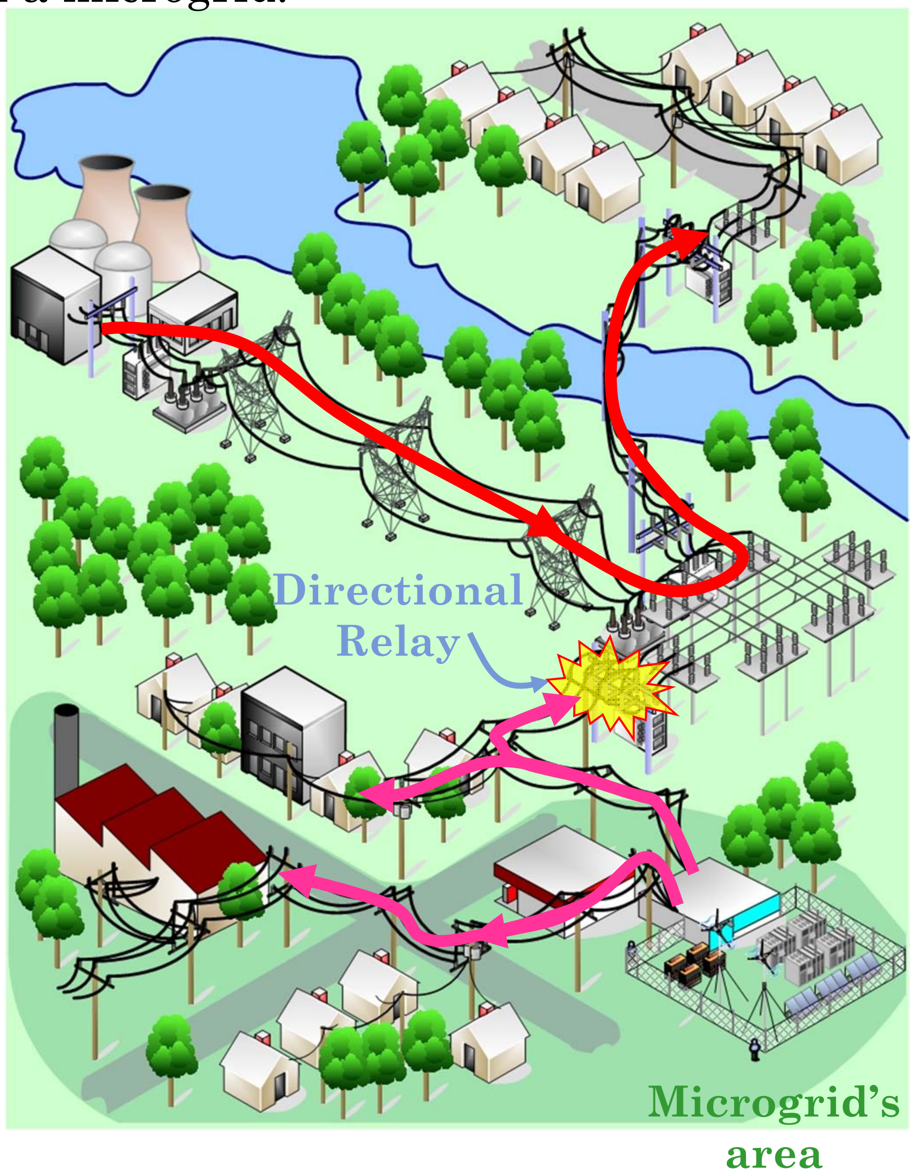
Microgrids and the grid interaction

- Initial normal power flow direction



Microgrids and the grid interaction

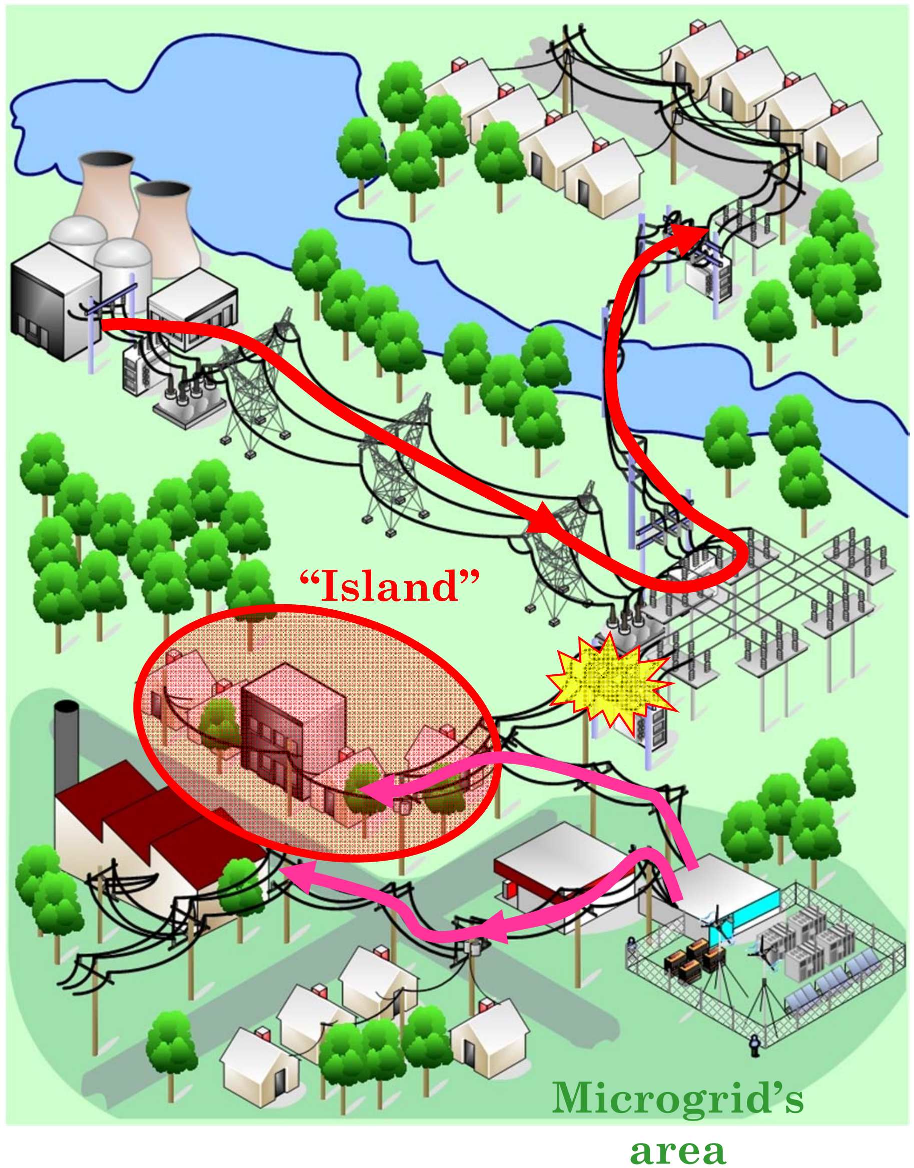
- New power flow with a microgrid.
  - The microgrid's power trips open the directional relay
  - Is it possible to change the grid's state fast enough to prevent voltage collapse caused by the sudden load changes introduced by the microgrid?
  - Can the microgrid stop injecting power back into the grid (i.e. prevents islanding)?



MICROGRIDS AND THE GRID INTERACTION

- Islanding.
  - If islanding occurs the microgrid will continue to provide power to a portion of the grid even though the grid connection upstream has been interrupted.

  - Potential issues:
    - Utility crews safety.
    - Power quality at the energized portion could be poor.



Electricity Market

- Current practice: Fixed market
  - Few producers, less competition
  - Regulated by government
- The future : **Free market**
  - Many producers (wind, solar, …)
  - Less regulation

GOAL

- Setup a Electricity market
  - Self interested (producer, buyer, grid owner)
  - Free (no central regulation)
  - Efficient (no overload, no shortage)

Design

- Trading Mechanism
  - Buy/sell electricity
- Overload Prevention Mechanism
  - Transmission charge
- Online Balancing Mechanism
  - Price for extra demand and supply in real-time

PROPOSED ELECTRICITY TRADING

Quantity Price

A day ahead electricity market

Electricity Market								
Market Price: 36.50, Volume=501.49								
Buy Orders					Sell Orders			
Buyer	q_b	p_b	n_b		Seller	q_s	p_s	n_s
b_8	1.9	36.9	n_8		s_7	5.350	36.44	n_7
b_9	0.849	36.62	n_9		s_4	2.350	36.76	n_4
b_2	7.2	12.98	n_2		s_6	9.0	37.44	n_6
					s_1	8.05	38.04	n_1
					s_9	7.1	38.33	n_9

- A day ahead market
  - Based on prediction of a day ahead demand/supply

Online Balancing Mechanism

- Balancing unpredictable demand/supply on real-time basis
  - + demand
    - need to buy at market price
  - - demand
    - Need to sell at market price
  - - supply
    - Buyer need to buy at market price

The Future

- The Smart Grid Program is not a 1 or 2 year activity. It will take 20 or 30 years to fully mature.
- Smart Grid provides intelligent, advanced power control for the next century.
- There will be significant improvement in tools, technologies and methods related to sensing, controlling, human interfaces.
- We need to consider seriously what part we want to play and what are some unique needs of the program that we can specifically address