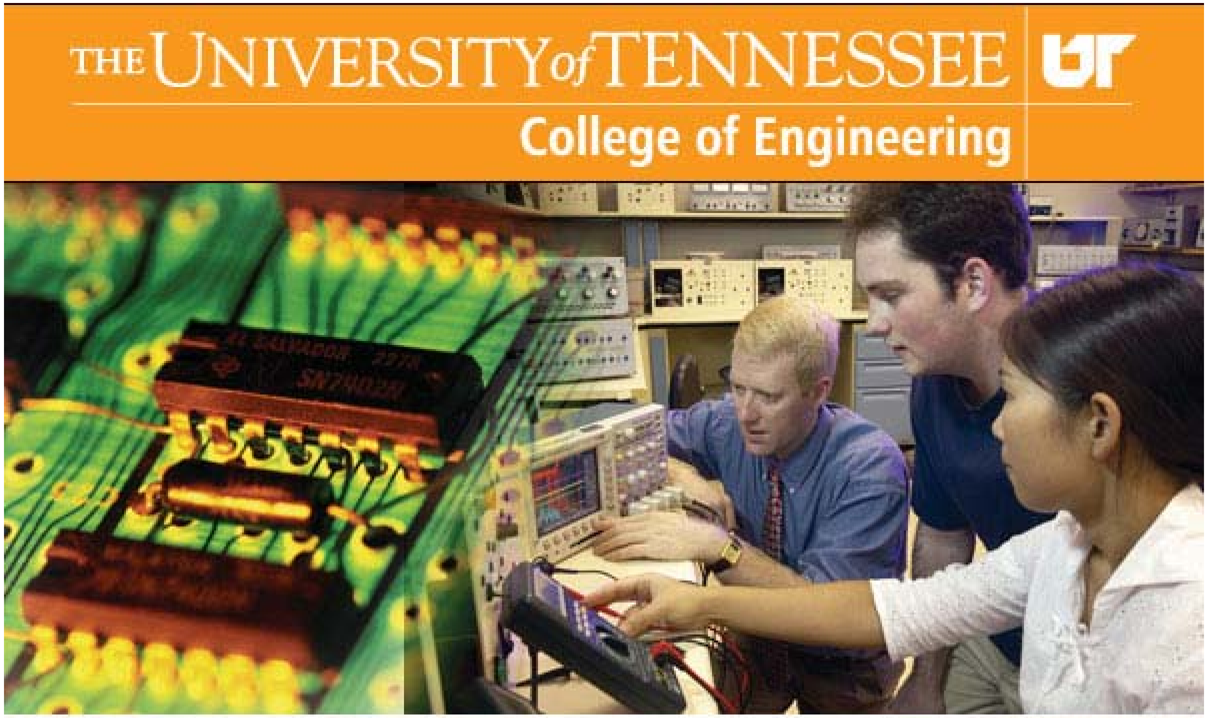

Power System Control Research Issues

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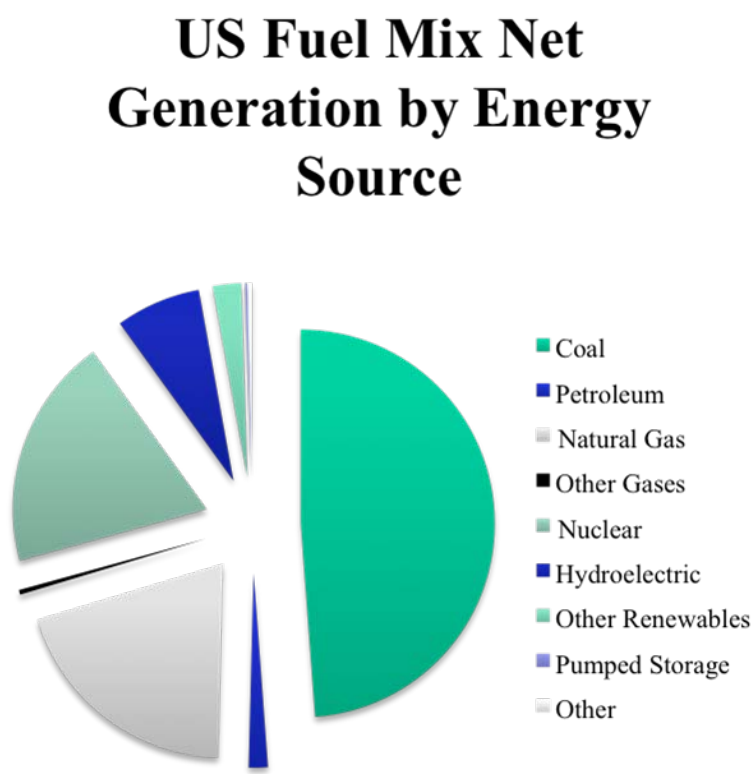
US Fuel Mix for Electricity
By Energy Delivered

- Net Generation, by Energy Source (2006, GWh)
  - Coal (1,990,926)
  - Petroleum (64,364)
  - Natural Gas (813,044)
  - Other Gases (16,060)
    - Blast Furnace gas
    - Propane gas
    - Other manufactured and waste gasses derived from fossil fuels
  - Nuclear (787,219)
  - Hydroelectric (289,246)
  - Other Renewables (96,423)
  - Hydroelectric Pumped Storage (-6,558)
  - Other (13,977)

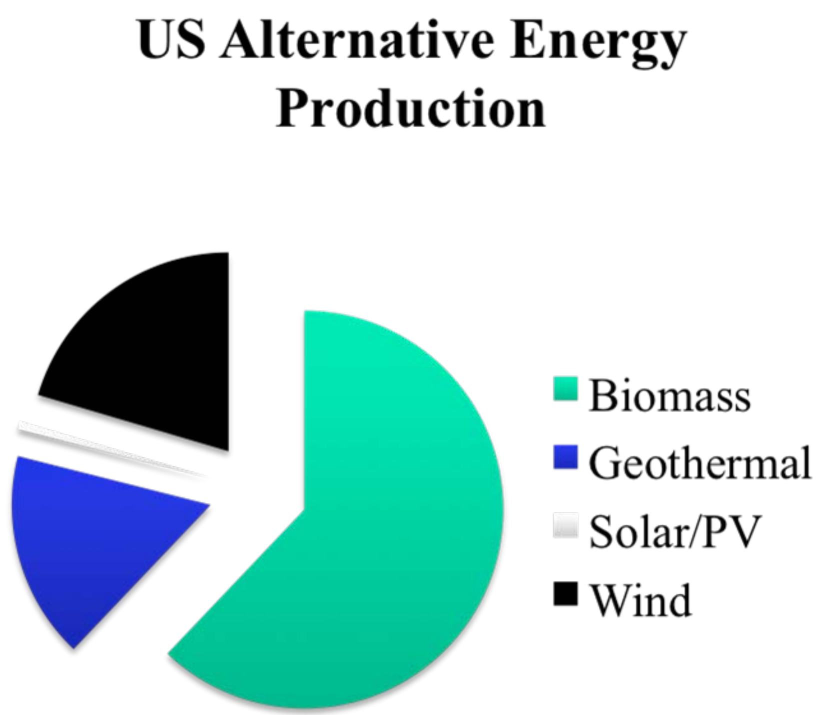


Some First Observations/Opinions

- Biggest contributors to CO_2 emissions are transportation and electricity
- Easiest ways to reduce CO_2 emissions
  - Reduce coal usage in electric power systems where alternatives can be found
  - Shift some transportation load to electric power grid
  - Greater use of electricity waste heat (CHP)
  - Increase use of petroleum alternatives in transportation (ethanol, biodiesel, methane, etc.)

US Alternative Energy Production

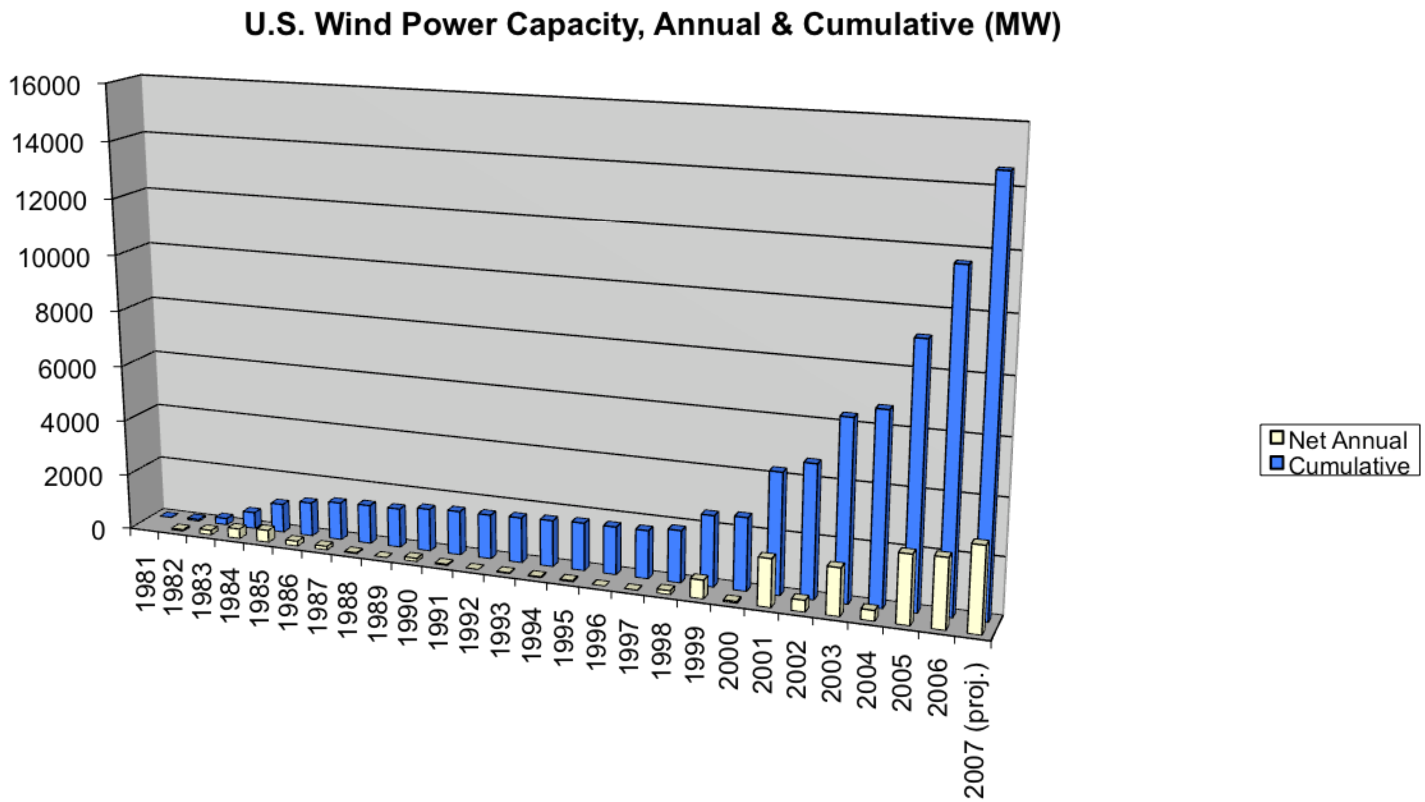
- By Source (2005, GWh)
  - Biomass (54,160)
  - Geothermal (14,691)
  - Solar/PV (550)
  - Wind (17,811)



Some More Observations / Opinions

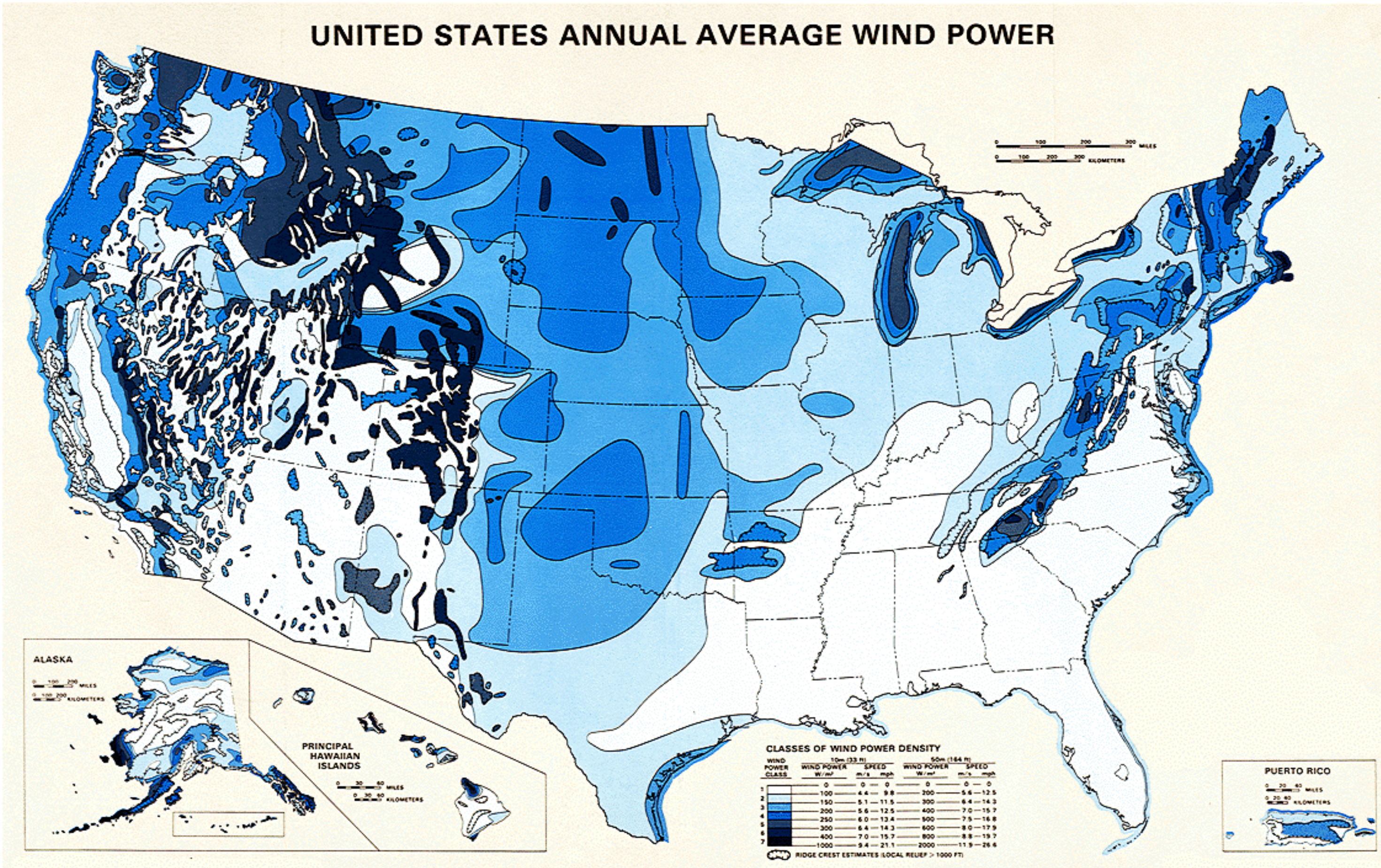
- Considering cost, availability of sites, development of technology, medium term (5-10 years); carbon limited generation will be dominated by
  - Wind – both on-shore and off-shore
  - Solar – to a lesser extent but depends on ability to compete at retail level
- Problems with wind and solar
  - Wind highly stochastic (variable)
  - Seasonal variations
  - Solar diurnal cycle does not match load

US Wind Resources



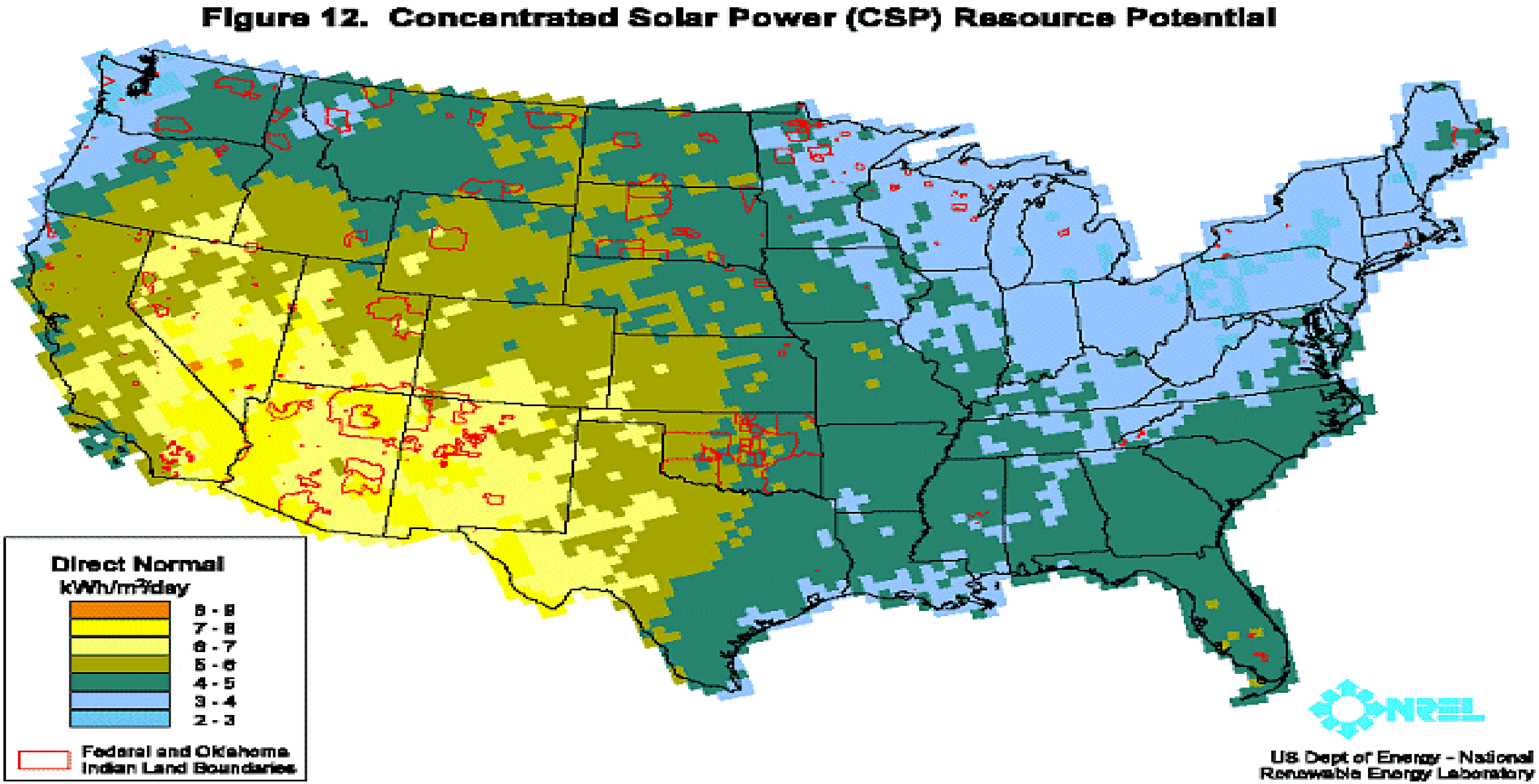
http://www.awea.org/Projects/growth.xls

US Wind Resources



http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-01m.html

US Solar Resources



http://www.eia.doe.gov/cneaf/solar.renewables/ilands/fig12.html

Challenges

Assume 50% Renewables is Desired Level

Many alternative sources are:

- less predictable than traditional fuel-based power plants;
- tend to be far from load centers so power may have to flow through congested transmission paths;
- do not generally match the daily cycle of load variation;
- suffer from unusual operating constraints, such as, rapid variation or complicated weather dependence;
- need to be tightly coupled to storage, which may be mobile.

Recent Experience with Wind

- Texas – Feb 2008.
  - 1700 MW dropped to 300 MW over several hours. Required drop of non-firm load. Press tended to blame wind but both forecasted load and dispatched generation were in error.
- California
  - California ISO requiring significant new reserves to meet ramp rate constraints brought on by wind units
- Washington State and Spain
  - Both report events of losing up to 1 GW in under a minute
- Major Issue is cost – either new reserves or new transmission

Existing Power System Control

- Connected system built upon rotating machines with high inertia and relies on dependable patterns of consumption
- Very little load is controllable, instead generation tracks daily load curve
- System engineered to meet peak demands
- Numerous centralized controls acting largely independent
- Localized control schemes primarily for protection

➔ Driven by reliability and fuel costs. Current system does have many advantages including high efficiency (from electrical viewpoint) and high reliability.

Overall Control and Communication Structure

- Largely hierarchical and centralized
- Controls separated by time frame and reach (day ahead scheduling, load frequency, voltage, real-time economic dispatch, static security, transient stability, etc.)
- Most communication flows up to control center (little from substation to substation)
- Pricing driven mostly by generation scheduling considerations
- Little customer choice in level of reliability

More Comments on Existing System

- A system solution is mandated mostly by reliability:
  - completely distributed options tend to fail in terms of reliability and affordability,
  - existing system tends to fail in terms of adaptability and sustainability.
- Can existing systems be adjusted incrementally? No, because of scalability
- Existing overall control is a “frozen accident” (a patchwork of controls - transient stability, load frequency, voltage, power quality, protection), largely uncoordinated
- Controlled entities (generators) are assumed to be in the hundreds, not millions

Needed System Changes

- a broader electric grid to include end energy use.
- increased scheduling capability through load management for existing loads and the addition of new load
- new and reconfigurable transmission to improve source diversity
- provide effective storage through a combination of fast start units, PHEVs, low-level UPS, and utility scale storage
- a “flattening” of the control structure that replaces the traditional control strategies with simpler local controls operating within a more global context for the system

Some Potential Research Issues

Control Challenges

- Speed of response
  - Milliseconds (power quality)
  - Seconds (transient stability)
  - 10s of seconds (small signal stability)
  - Minutes (voltage stability and system viability)
  - Days
  - Seasonal
- Amount of response
- Need for new transmission
- Determining transmission limits in real time

Example Control Issues

New Load Controls

With 50% renewables at 40% capacity factor

- Need 600 GW nationwide and can easily have 100 GW of variation to manage (expensive to do with reserve gas units)
- How much load is controllable in the US?
  - Heating/Cooling (35.2 aGW assuming 20% controllable)
  - Lighting (20 aGW assuming up to 50% controllable)
  - Industrial (23 aGW assuming up to 15% controllable)
  - Light electronic load (12.9 aGw assuming up to 15% controllable)

➔ This would be a massive change but probably still doesn't get you far enough if you want to avoid increasing reserves

Possible Solutions
New Controllable Load

- PHEV's
  - Plug in hybrid vehicles
  - Use as storage
  - Use as controllable load – peak shaving, load leveling

Example

- 6kWh load
- Average 5 hour charge time
- 20 million in US
- 24 aGW of controllable load

- Hydrogen production
  - Could couple with wind units

- Potential huge but market for hydrogen probably some time off

Possible Solutions
Flatness as a Control Structure

Our proposed control scheme combines:

- local control for speed and robustness (corrects for uncertainty),
- global (area) control that selects one of finitely many modes for each local controller, e.g., efficiency maximization, cost minimization, stabilization, network recovery. This level compensates for possible myopic actions of uncoordinated local controls.

Divide and Conquer…

Flatness should allow the system operator to systematically generate feasible plans in a relatively simple way by employing a two-degree-of-freedom approach that separates overall scheduling into:

1. Nominal generation plan (performed on a global level),
2. Local (typically fast) tracking and stabilization.

➔ Cost is some loss of overall efficiency

Possible Solutions

Transmission System Enhancement with FACTS Controllers

- Conventional methods of transmission planning is linked to large coal/nuclear generation sites – no longer the case with renewables and in restructured power markets.
- Flexible AC Transmission Systems (FACTS) controllers can be strategically located to strengthen flow paths for renewable sources at a much lower cost than new transmission lines. Voltage-sourced converter based controllers are versatile and reconfigurable – for example, the Marcy Convertible Static Compensator (CSC).
- Local (flat) control and coordination of FACTS controllers for active flow control and voltage support need to be investigated – new dispatch and coordination schemes for steady-state and transient operations.
- Use of high-sampling rate synchrophasor data can further improve the response of FACTS controllers to counteract disturbances.
- Need for computer simulation tools and test systems to other researchers in renewable energy community.

Conclusions

- Wide area interconnected electricity grid central to solving energy problems
- Wind has perhaps the greatest potential – problems of variability may have been overstated by media BUT a new control structure is needed to address greater demand side response and new storage
- Need for storage has been overstated
- Shifting of greater load to grid has benefits both for reduced emissions and for ease of control
- Need for new transmission flexibility and reconfigurability
- Must get the economic incentives right

Discussion