Network Science & Systems Theory Can Accelerate Clean Energy Technology Adoption by Providing Today the Benefits that Storage Technology Research may Provide in 10 Years

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Limits to Clean Wind Electricity Generation Penetration

- Wind Electricity Generation is Today Competitive on its own Right. Fully Loaded Cost may be recovered at $70/MWh.
- **Today**, in Denmark, Spain, Germany Wind Generation Represents 20-35% of Installed MW and Provides 12-18% of Generated MWh
- US Penetration TODAY 1%! **US Target** **20% of KWh by Mid Century** (src:The En. Imperative, Exec Off of the Pres. Nov 2006). **EU Target** **20% of ALL PRIMARY ENERGY – not just KWh -- by 2020**!
- BUT **10-15% of KWh** Penetration is almost a **Hard Limit** in the sense that Additional Penetration of wind or other Uncontrollable Generation, Results in significant costs from:

a) Excessive Cycling (shut downs and start ups) of Conventional Generation required to absorb Renewable Generation at low load times (e.g. during the night)

b) Increased Reserve Requirements for Load Balancing and Unplanned Generation/ Transmission Outages

c) Incrementally Higher Conventional Fuel Consumption and CO_2 Emissions

Will Argue Limits May Be Lifted To Great Advantage By:

- Creating New Electricity Load which
  - Substitutes CO_2 Producing Fuel (Gasoline) Bridging Power and Transportation Sectors
  - Is Amenable to Load Management and thus Offers Inexpensively Benefits Similar to those Expected of Future Storage Devices
- Supplying this New Load with Wind Energy Generated Power

Greenhouse Gas (CO_2) Contributions in the US

• Electricity Generation	33.3%
• Transportation	27.9%
• Industry	19.6%
• Commercial	6.6%
• Agriculture	7.0%
• Residential	5.6%
TOTAL	100.0%

Source: EPA;U.S.D.A Forest Service, NY Times, April 3, 2007

Some Simple Accounting

- If Wind Generation Provides 15% of total KWh – the practical Upper Bound Under Today's Conditions – It will Reduce Overall CO_2 Emissions by .15x.33~5%
- Hybrid Vehicles Reduce Fuel Consumption and hence CO_2 emissions by 40%. If half of all vehicles are Hybrids by 2030, Overall CO_2 reduction will be .5x.4x.28~6%
- Conversion of Hybrids to Plug-ins Improves Fuel Savings from 40% to 80% or more, for an Additional Overall CO_2 reduction of 6% or more.

Hybrid Plug-ins

Small Sedan 15-40 Mile Storage (3-9 KWh)

source: http://hybridinterfaces.ca/otherbats.html; NY Times, M. L Wald, February 24, 2007, and www.a123systems.com*; IEEE Spectrum, April 2007**

Battery Type	Cost, $	Weight, Kg/KWh	Charging Cycles/Life
Lead Acid, 3KWh	1,100	46	300
NiMH, 3KWh	2,400	21	500
Li 3KWh	5,000	15	~1,000
A123Syst*, Li 9KWh, Recharge time 45 min	10,000	9	~7,000
Tesla**, Li 16KWh, Recharge time 3.5 h	???	6	~5,000 (??)

Can CO_2 Reduction from Plug-ins Come from Wind rather than Coal Generation?

- Advantage of Battery-Charging-Load: Ability to Manage it so that it Presents a KWh Energy Requirement over a period of time Rather than a non-negotiable Instantaneous KW Power Requirement
- If Battery Charging is Managed Properly, it is Capable of Removing the Limits on Wind Generation

Reserve Market Services are Energy Market Derivatives Priced by Solving on a 1) day ahead, 2) hour ahead, and 3) real time basis, the problem:

Minimize cost of Energy Injections and Reserves as Bid by providers minus Value of Loads as bid by Load Representatives

Subject to:

- Sum of Injections = Sum of Loads
- Reserves provided >= Required Reserves, multiple types primary, secondary, tertiary including ancillary services such as reactive power
- Transmission System Constraints, thermal, voltage angle, n-1 contingency, etc.
- Distribution Network (local) Constraints, transformer overloading, etc.

Desired Characteristics of Battery Charging Management

Battery Charging may be Managed to Provide:

- Scheduled Balancing of Predicted Load Net of Wind Generation (Function of day ahead hourly markets)
- Fast Tertiary Reserves (~10 min. or spinning reserves when offered by generators) or Slow Tertiary Reserves (20 min +, or stationary reserves Offered today by Generators)
- Super Fast Reserves (~ 5 sec Response Provided Today by Generating Units on AGC). Include Primary and Secondary or Regulation Reserves

Note: Since Charging Loads are Distributed and Feeding to Distribution Network, Reserve Services are Capable of Safeguarding Local Distribution Network Overloading Constraints!

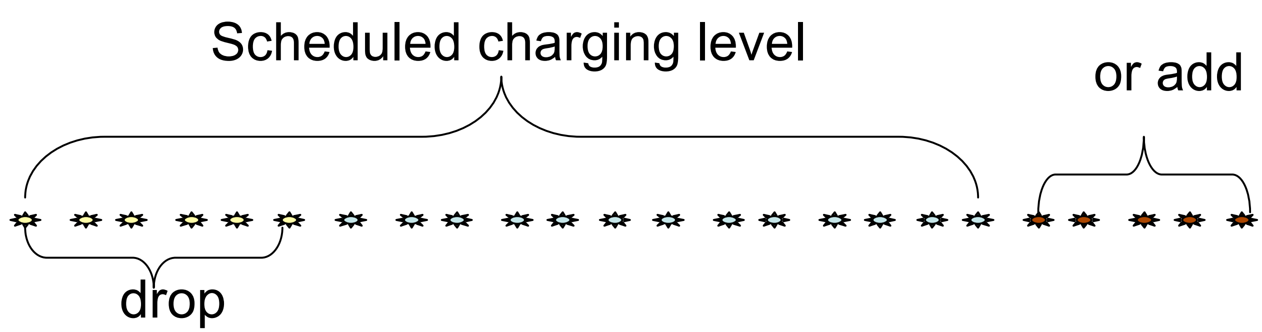
Scheduled Balancing of Predicted Load Net of Wind Generation

- Predictive Wind Generation Systems Process Meteorological Forecasts and Geography Information (particularly Important in Mountainous Regions) to Attain error bounds of 20% on a day ahead basis, 5% on an hour ahead basis.
- Average Hourly Charging Loads may be Scheduled Accordingly to Exploit Day Ahead Hourly Clearing Prices

Super Fast Reserves

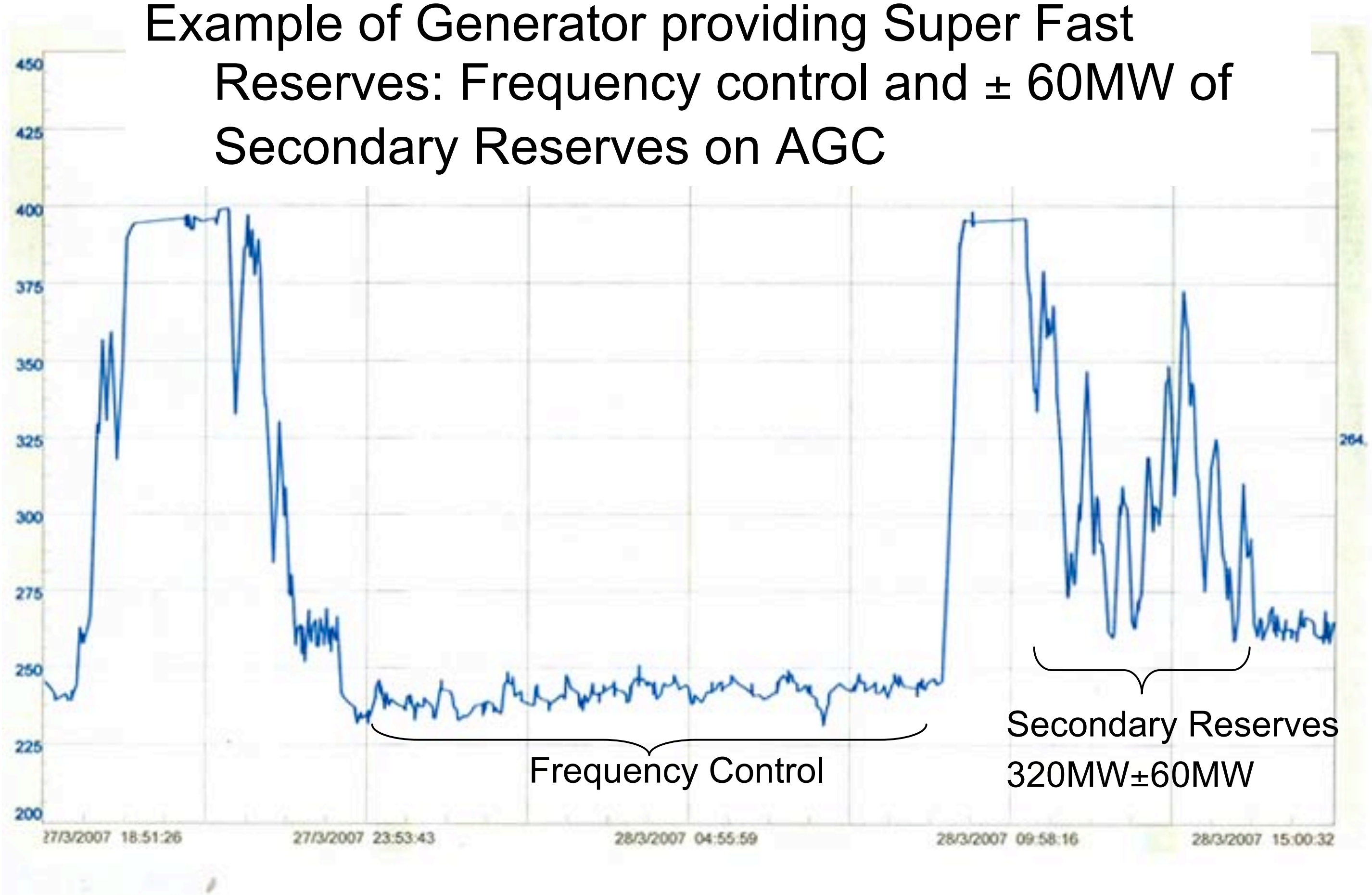
Charging Load can Provide Fast Modulation about the Reference Day Ahead or Hour Ahead Charging Schedule.

Example Algorithm:Order Charging Demands in Ascending Magnitude of Required Energy and Drop or Add Requisite Amount of Demand Points within seconds to Respond to Super Fast Secondary Reserve Requirement Command from Control Center



Today Generating Units are Only Reserve Providers

Example of Generator providing Super Fast Reserves: Frequency control and ± 60MW of Secondary Reserves on AGC



Source: Courtesy of EnThes Inc., March 2007

Fast Tertiary Reserves

- Charging Load May provide Tertiary Reserves (Fast or Slow) by Promising to Drop all of its Day Ahead or Hour Ahead Scheduled Load as Required.
- The Promise will not be Called Upon often, but, when it is, it will Result in Substitution by Gasoline of KWhs not Charged.

Are Reserve Markets with both Generating Units and Load Participating on a Par Basis Feasible?

- PJM, the Largest Regional Transmission System Operator in the US is Accepting Reserve Services from Load Since July 2006. Experience so far Indicates that Services Offered by Loads are More Reliable than those Offered by Generating Units!
- New England ISO is presently Conducting Pilot Studies to Investigate Load Participation in Reserve Services.

Reserve Markets Allowing Participation of Distributed Loads Require:

- Institution/Implementation of Reserve Markets with Load Participation as in PJM. However we note that although PJM Accepts Super Fast Reserves offered by Loads, No Load Entity has Offered them yet!
- Cyber Infrastructure Capability Requirements: Identify in Real Time (time scale of seconds to 10 minutes)
  - Location of Demand Point (plug-in requiring charging)*
  - Charging Energy Demanded and Period over which Charging is Desired*
  - Range of Acceptable Charging Capacity*
  - Condition of Distribution Network and Associated Constraints *
  - System/Regional Balancing Requirements (from Control Center)*
  - Control Charger of Each Plugged-in Battery**

*Inputs **Outputs

Research Issues

- Price Discovery of Reserve Services Markets and Distribution of Reserve Costs
  - How are Reserve and Energy Prices Related? What are Efficient ways to Recover Cost of Reserve Services? In other words, How are these Costs to be Distributed Amongst Load Representatives?
  - Are Markets too Thin to be Competitive? Particularly when Local Distribution Network Constraints are Active?
  - How is the Overall Cost of Providing Reserves (and generally Ancillary such as Reactive Power) Services Likely to Decrease with Load Management?
  - What is the Expected Value to be Recovered by Storage-Type Loads Participating in the Reserve Markets? How will this Value Decline as the Supply of Load Provided Reserves Services Increases?

Research Issues, continued

- Feasibility, Design, and Cost of Cyber Infrastructure:
  - Bi directional Communication:Receive Information and Send Control Commands to Charger
  - Detect Condition of Distribution Network to Ascertain/Estimate Overload States
  - Robustness/Reliability of Cyber Infrastructure
  - Efficiency and Cost

Research Issues, continued

- Technology Related Research
  - Evolution of Batteries to Attain Larger Number of Charging Cycles without Decrease of Life, Store More Energy per Weight, etc
  - Evolution of Chargers

Research Issues, continued

- Use/Operation of Cyber Infrastructure
  - Information Dissemination
  - Collaboration with Sensors Ascertaining the State of the Distribution Network
  - Intelligence/Optimization/Control in Managing Individual Charging Demands in order to Satisfy these Demands while Providing Various Reserve Services that meet System and Local/Regional Requirements
  - Investigation of Autonomous Distributed “Homeostatic Control” Opportunities (example: FAPAER, Frequency Adaptive Power Energy Regulator)

Business Opportunities

- ESCOs for Battery Charging Management
- ESCOs for Aggregated Load Management (e.g. Air Conditioner Cycling etc.)
- Cyber Infrastructure:
  - Back bone to Control Center,
  - Power Line Modem to Substations for Input/Output Communication and Distribution Network State Detection and Communication
  - Last 100 feet input/output communication,
  - Wind Speed Sensors
  - Wind Generation Forecasting
- Technology:
  - Batteries, Chargers
  - Wind Generation Parks

Some Approximate Benefits/Costs Relevant to Evaluating the Business Opportunity

- Secondary Reserve Services in NE and PJM are worth $10-$20 per MW in band provided (+ or – injection) per hour
- Fast Tertiary reserves at PJM may be bid with a cap of $7 per MW on stand-by per hour, hence value is in range of $3-$5 per MW per hour
- Hourly prices in New England are flat during 8-9 months with ~ 20% variation over the daily cycle, but during 8-12 weeks they vary as much as from $50/MWh to $500/MWh
- Capacity Obligations can be met in NE and PJM at ~ $60,000 per MW per year. Fully Interruptible loads such as Battery Storage should normally have NO capacity obligation
- Carbon Taxes in Europe have varied from $5-$30 per ton of CO2.
- CO2 emissions in tons/MWh:~ 1.2 Coal gen; 1.0 Oil gen; 0.6 NG gen
- Wind Generation from Large Units (1-5MW) is Economically Viable at Electricity sales prices of $70-$80/MWh
- 1 liter of gasoline produces ~ 4kg of CO2 emissions.

Conclusion

Based on plug-in Hybrid Vehicles and the Creation of Load Participating Reserve Services Markets, a Bridge between the Power and Transportation Sectors can be Established to Enable a Substantial Increase in Wind Electricity Generation with Dramatic Impact on CO_2 Emissions.

The Combination of Existing-Technology-Based Cyber Infrastructure Development with Network Science and Systems Theory may Provide the Impetus for Significant Business Development

CISE Sensor Network Consortium Proposes Pilot Study!

Participants Sought in Various Fields

•Cyber Infrastructure: Amperion, Millennial Net?, others

• ISOs: New England, PJM, Others (NY, Texas, California)?

•Hybrid Conversion to plug-in companies: A123 Systems, Tesla, GM,Toyota, Honda?

•Aspiring ESCOs

•Other Dispersed Loads Interested in providing Reserve Services: Housing projects/ Cooperatives, Army Bases?

•Wind Parks, other Renewable Energy Electricity Generators?

•Intelligent Control in Reserve Provision: CISE faculty, other Universities/Research labs?

•Reserve Market Rules, Contracts. ISOs, FERC, PUCs, BU Faculty (CISE, Economics dept, SMG), Other Universities and Research Labs?