Improving the Power Grid Performance in the Complex Environment

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Dr. Damir Novosel
President, Quanta Technology

Overview:

- Industry Trends
- Renewable Energy Portfolio Incentives, Opportunities, and Challenges
- Case Studies
- “Smart Grid”
- Conclusions

Emerging Trends in Energy Investments

Society mindset changing and new sense of urgency to all energy issues, including the grid

- Oil Dependency
- Environmental concerns
- Increasing customer expectation for uninterruptible power

Electrical Energy is only viable new energy source

- Renewable energy (wind, solar, geothermal, bio-mass, ocean tide, etc.)
- Energy storage (including PHEV)
- Carbon Sequestration Technologies
- Energy efficiency and DSM (w/ peak load shaving)
- Nuclear power

Complex infrastructure requires "Smart Grid" Solutions

Smart Grid Spans the Supply Chain

- Customer Load Participation
  - Flatten the demand curve or shape it to coincide with renewables
- Distribution
  - Enable customer/utility interaction for efficient and reliable operation
- Transmission
  - Improve Wide Area Monitoring, Protection and Control:
    Grid is more complex and congested
- Generation
  - Sustainable generation portfolio

Use of advanced technologies to improve the *performance* of electric utility systems to address the energy needs of society."

- *Efficiency and Utilization*
- *Renewable Energy Utilization*
- *Demand Response*
- *Power Quality and Reliability*
- *…*

2009 Stimulus Bill – Energy Related Allocations

DEPARTMENT OF ENERGY- ENERGY PROGRAMS

Energy Efficiency and Renewable Energy (EERE) – $5.6 B

- $3.1 billion for the Department of Energy's (DOE's) State Energy Program
- $2.5 billion for Department of Energy science programs
- Funding to state energy offices for energy efficiency and renewable energy programs

Energy Efficiency and Conservation Block Grant Program (EECBGP) – $3.2 B

- $2.8 billion is awarded based on existing formula.
- $400 million shall be awarded on a competitive basis.

Green Jobs – $0.5 B

- Prepare workers for careers in energy efficiency and renewable energy.

Advanced Research Projects Agency — Energy (ARPA-E) – $0.4 B

2009 Stimulus Bill – Energy Related Allocations (2)

Transmission Upgrades – $6.51 B

- $3.25 billion for the Bonneville Power Administration
- $3.25 billion for the Western Area Power Administration
- $10 million for Western Area Power Administration construction and maintenance

Advanced Batteries - $2.9 B

- $2 billion for grants to assist U.S. companies in the manufacturing of advanced battery systems and components
- including advanced lithium ion batteries, hybrid electrical systems, component manufacturers and software designers
- $0.3 billion will support an Alternative Fueled Vehicles Pilot Grant Program
- $0.3 billion for energy efficient appliances
- $0.3 billion for state and local governments to purchase energy efficient vehicles

Plug-in Electric Vehicles - $0.4 B

- $400 million for the Plug-In Electric Drive Vehicle Program

Energy Conservation Bonds - $4 B

- $2.4 billion for qualified energy conservation bonds.
- $1.6 billion in new clean renewable energy bonds.

Weatherization Assistance Program (WAP) - $5 B

- $5 billion for Weatherization Assistance Program

2009 Stimulus Bill – Energy Related Allocations

Electricity Delivery and Energy Reliability (EDER) - $4.5 B

- To modernize the electric grid, including demand responsive equipment and energy storage

Department of Defense - $3.675 B

- $0.075 billion for Defense-wide funding for R&D (incl. energy from renewable)
- $3.6 billion for DOD energy efficiency projects and modernization of facilities

Federal Buildings - $4.5 B

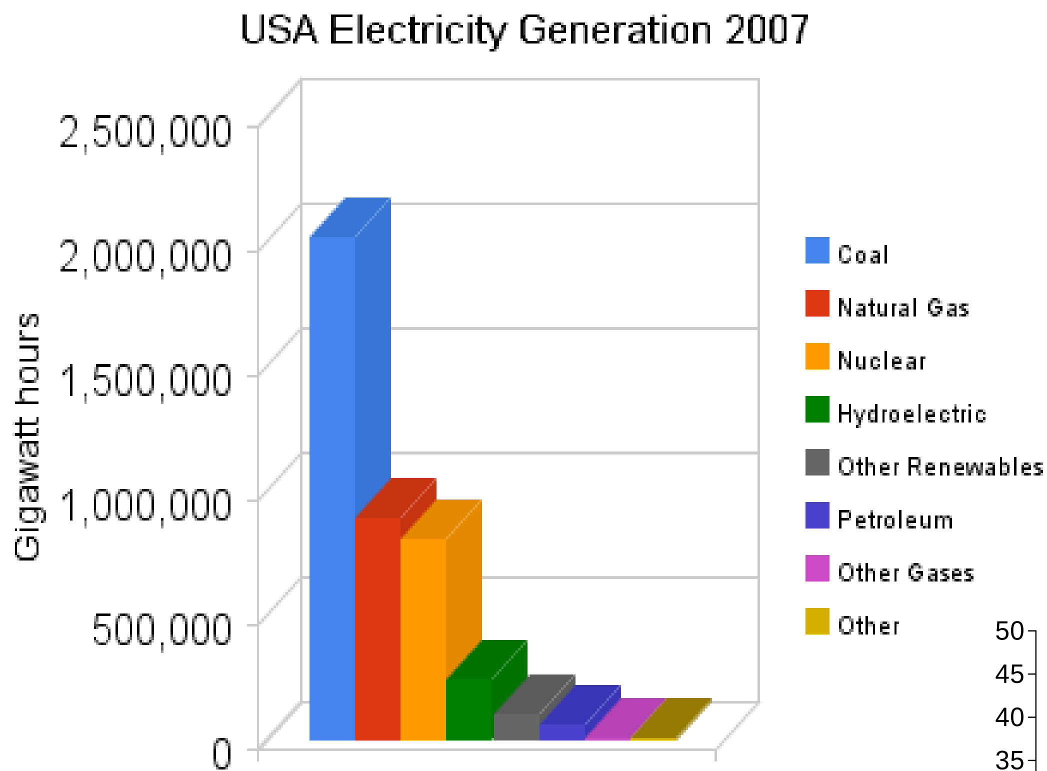
- $4.5 billion convert GSA facilities to High-Performance Green Buildings.

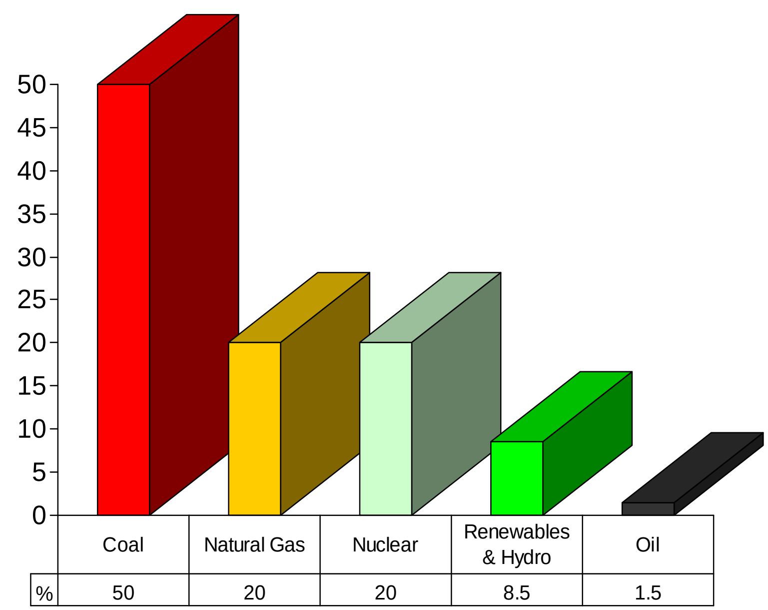
OTHER - $10.39 B

- $6 billion for Innovative technology loan guarantee for renewable energy and electric transmission technologies
- $3.4 billion for carbon capture experiments
- $0.39 billion for Uranium Enrichment Decontamination and Decommissioning Fund
- $0.5 billion for leading edge biofuel projects
- $0.1 billion for Electricity grid worker training

Renewable Energy Portfolio Incentives, Opportunities, and Challenges

US Electricity Generation





Wind and Solar Installed Penetration Levels

Region	Peak Load MW (2007/8)	Installed Wind MW (2008)	Wind Penetration	Installed Solar MW (2007/8)	Solar Penetration
Denmark	3,700	3,180	86%	N/A	N/A
Germany	82,800	23,903	29%	1,328	1.6%
Spain	43,400	16,754	39%	650	1.5%
The Netherlands	17,800	2,225	13%	N/A	N/A
India	107,010	9,645	9%	3	0.0002%
China	409,000	12,210	3%	820	0.2%
Continental USA	785,930	25,170	3%	226	0.003%
Texas	62,188	4,296	7%	N/A	N/A
New Mexico	1,500	497	33%	N/A	N/A
Japan	182,690	1,880	1%	226	0.12%

Eligible Technologies Under RPS Requirements

Energy Source	AZ	CA	CO	CT	DE	DC	HI	IA	IL	MA	MD	ME	MN	MO (a)	MT	NC	ND (a)	NH	NJ	NM	NV	NY	OH	OR	PA	RI	SD	TX	UT	VA (a)	VT (a)	WA	WI
Biofuels		•					•		•	•								•			•	•				•						•	
Biomass	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
CHP/Waste Heat	•c		•	•			•			•						•	•				•		•		•		•		•			•	
Energy Efficiency				•			•		•					•		•					•		•		•							•	
Fuel Cell (b)				•								•	•d									•	•		•								
Geothermal	•	•	•		•	•	•			•	•	•			•	•	•	•	•	•	•		•	•	•	•	•	•	•	•		•	•
Hydro	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Landfill Gas	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•
Municipal Waste		•		•		•	•	•		•	•		•						•		•		•		•		•						
Ocean Thermal		•		•	•	•	•			•	•							•				•		•		•		•	•			•	
Photovoltaics	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Solar Thermal Electric	•	•		•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•		•	•	•	•	•	•	•
Tidal		•		•	•	•	•			•	•	•				•		•	•			•		•		•		•	•	•		•	•
Waste Tire																					•												
Wave		•		•	•	•	•			•	•					•		•	•			•		•		•		•	•	•		•	•
Wind	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

a) States with RPS goals not mandatory requirements.

b) Includes only those states that allow fuel cells using nonrenewable energy sources of hydrogen. Some states allow only renewable fuel cells (Arizona, California, Colorado, Delaware, Massachusetts, Maryland, Missouri, New Mexico, New York, Rhode Island, Wisconsin) as eligible technologies.

c) Renewable CHP systems are eligible; fossil-fueled CHP systems are not eligible.

d) After January 1, 2010, hydrogen must be generated by renewable energy sources.

Source: Database of State Incentives for Renewable Energy (DSIRE) last accessed August 2008

Technology: Costs

Levelized Costs of Electricity Production by Technology				
Technology	**Energy Source Fuel**	**Economic Lifetime (years)**	**Gross Capacity (MW)**	**Direct Cost Levelized (cents /kWh)**
Combined Cycle	Natural Gas	20	500	**5.18**
Simple Cycle	Natural Gas	20	100	15.71
Wind	Wind; Resource Limited	30	100	**4.93**
Hydropower	Water; Resource Limited	30	100	**6.04**
Solar Thermal				
Parabolic Trough	Sun; Resource Limited	30	110	21.53
Parabolic Trough-TES	Sun; Resource Limited	30	110	17.36
Parabolic Trough-Gas	Sun/Natural Gas; Partially resource limited	30	110	**13.52**
Geothermal				
Flash	Water	30	50	**4.52**
Binary	Water	30	35	7.37
Emerging Technologies				
Solar Thermal - Stirling Dish	Sun; Resource Limited	30	31.5	**15.37**
Photovoltaic	Sun; Resource Limited	30	50	42.72
Phosphoric Acid Fuel Cell	Natural Gas	20	25	21.27
Molten Carbonate Fuel Cell	Natural Gas	20	25	**10.15**
Solid Oxide Fuel Cell	Natural Gas	20	25	13.04

***Source: California Energy Commission, Comparative Cost of California Central station Electricity Generation Technologies*, Staff Report, publication # 100-03-001**

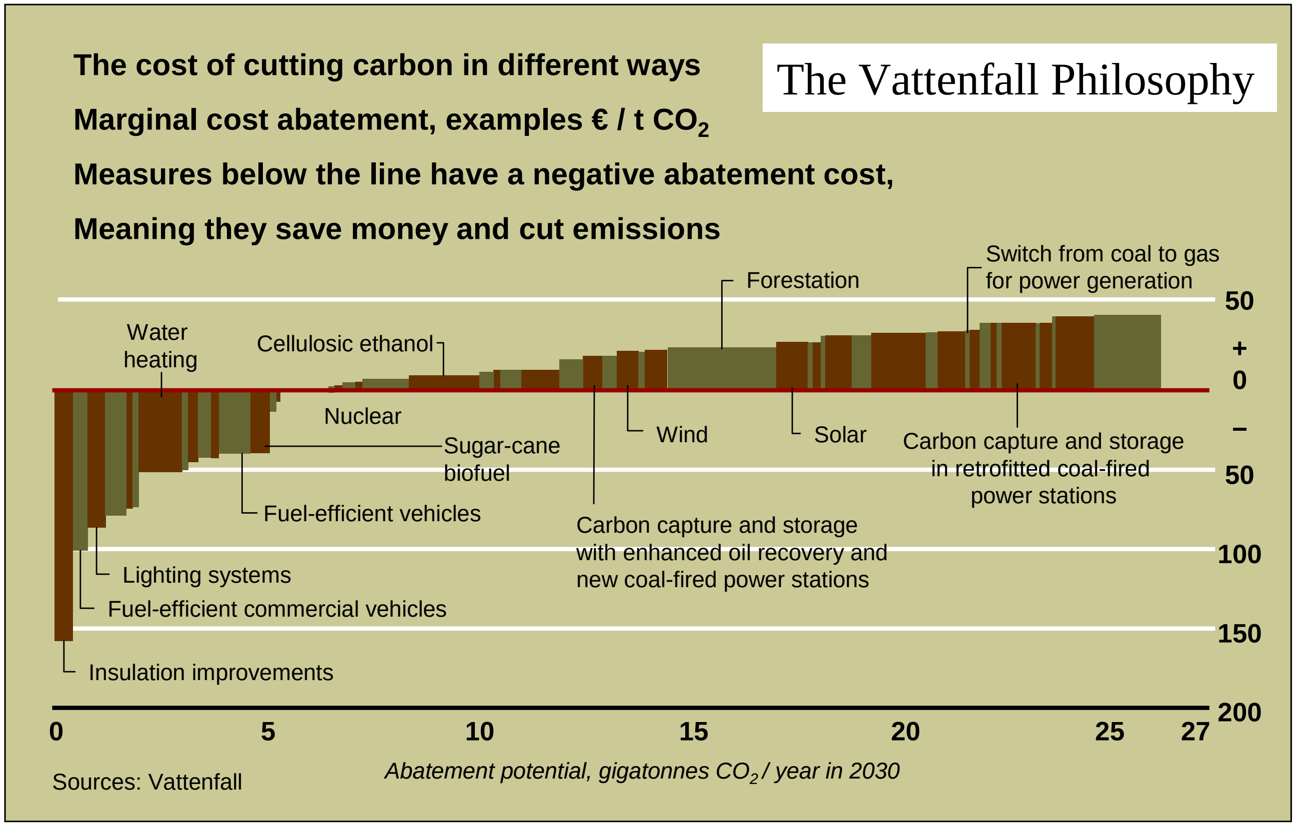
Top US Power Companies Carbon Risk

Utility	Emissions Disclosed tonnes, m	Cost of 25% Cut in Emissions @ $22/t $ M	% Turnover
American Electric Power	146.47	826.46	6.82
Southern Company	137.00	773.02	5.70
Progress Energy	58.06	327.60	3.24
TXU	50.00	282.13	2.70
FPL Group	47.35	267.17	2.26
First Energy	45.36	255.94	2.13
Public Service Enterprise Group	24.81	139.99	1.13
Constellation Energy	22.09	124.64	0.73
Exelon	12.61	71.15	0.46
PG&E	0.54	3.05	0.03

Source: Trucost, Economist Magazine June 2007

Carbon Emissions Reductions – Cost of Solutions

What are the costs in different regulatory environments?

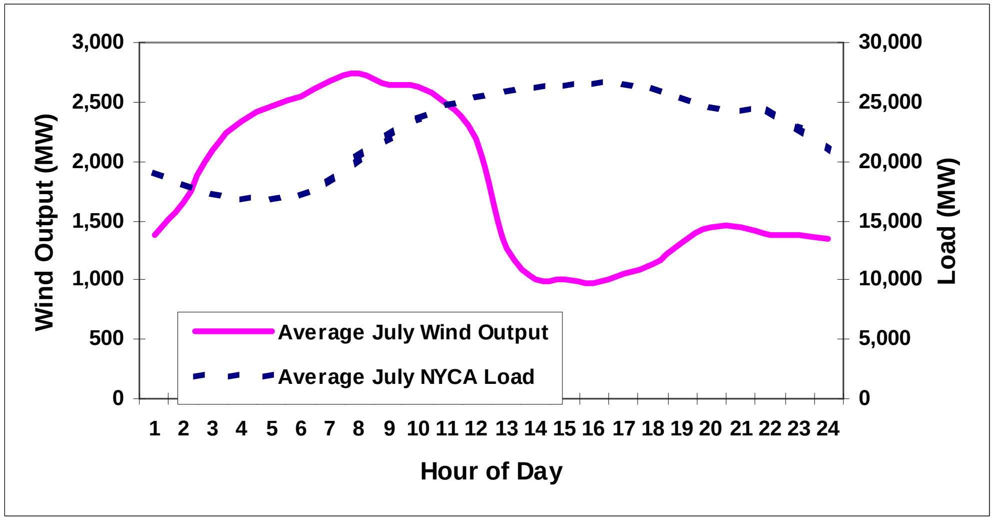


E.g. Lighting accounts for 19% of the worlds electricity use
Standard incandescent bulb costs 1 euro but uses 15 euros of electricity per year
CF bulbs cost 5 euros but uses only 3 euros per year; payback less than 1 year

A global carbon price of \$20 -50 (per tCO_2) would make most key carbon reducing technologies viable

Key Challenges to 20% Wind & Solar by 2020

- Investment and ROW of the nation's transmission systems (Interconnecting remote renewable generation)
- Weak interconnections
- Non-coordinated regional power balancing areas
- Intermittency
- Inaccurate forecasting
- Generator ramp-rates
- Off-peak renewable generation profiles
- Limited FACTS & HVDC
- Limited Energy storage



Renewable Energy Integration - Capacity Factor

- Capacity factor is the ratio of the actual energy produced, to the hypothetical maximum possible, i.e. running full time at rated power.
- Capacity Factor is Measure of System Utilization

$$CF = \frac{Average\ Power\ (kW)\ x 8760\, h/yr}{Rated\ Power\ (kW)\ x 8760\, h/yr} = \frac{Average\ Energy}{Maximum\ Rated\ Energy}$$

- Wind power: 20 – 40 %
- Hydro power (depending on size): 30 – 90 %
- Solar Photovoltaic (tracker & region): 12 – 25 %
- Nuclear CF: 60% - 100% (Avg. 92%)
- Thermal plants (e.g. large coal): 70 – 90 %
- Combined cycle gas plant: 60%
- Biomass thermal plant: 80%

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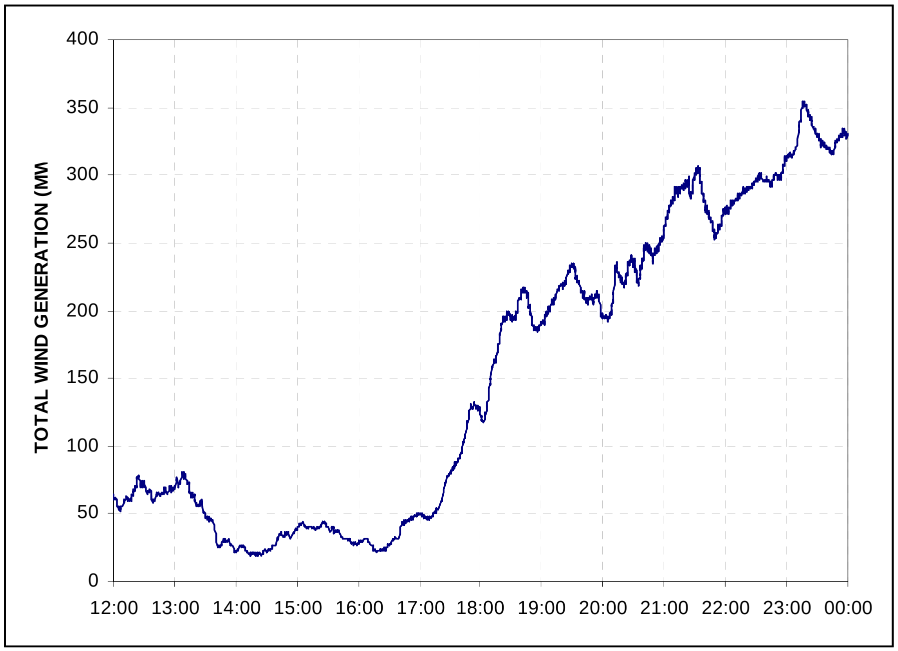
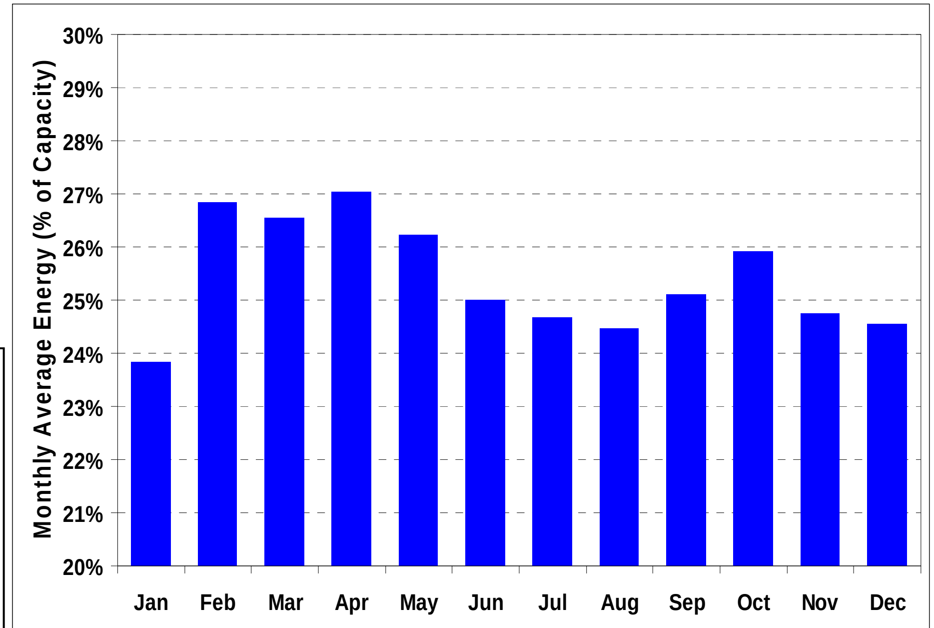
Wind Generation – Patterns & Capacity Factors

- Wind has daily and seasonal patterns
- Wind generation not correlated with load
- Approximately 25% annual capacity factor



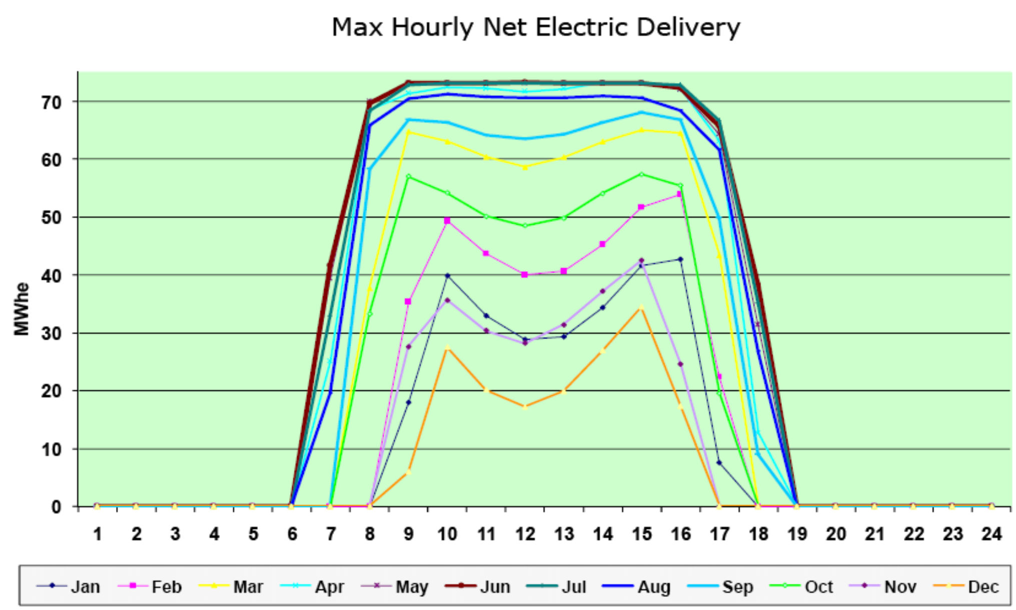
Wind Generation Patterns in the BPA control area



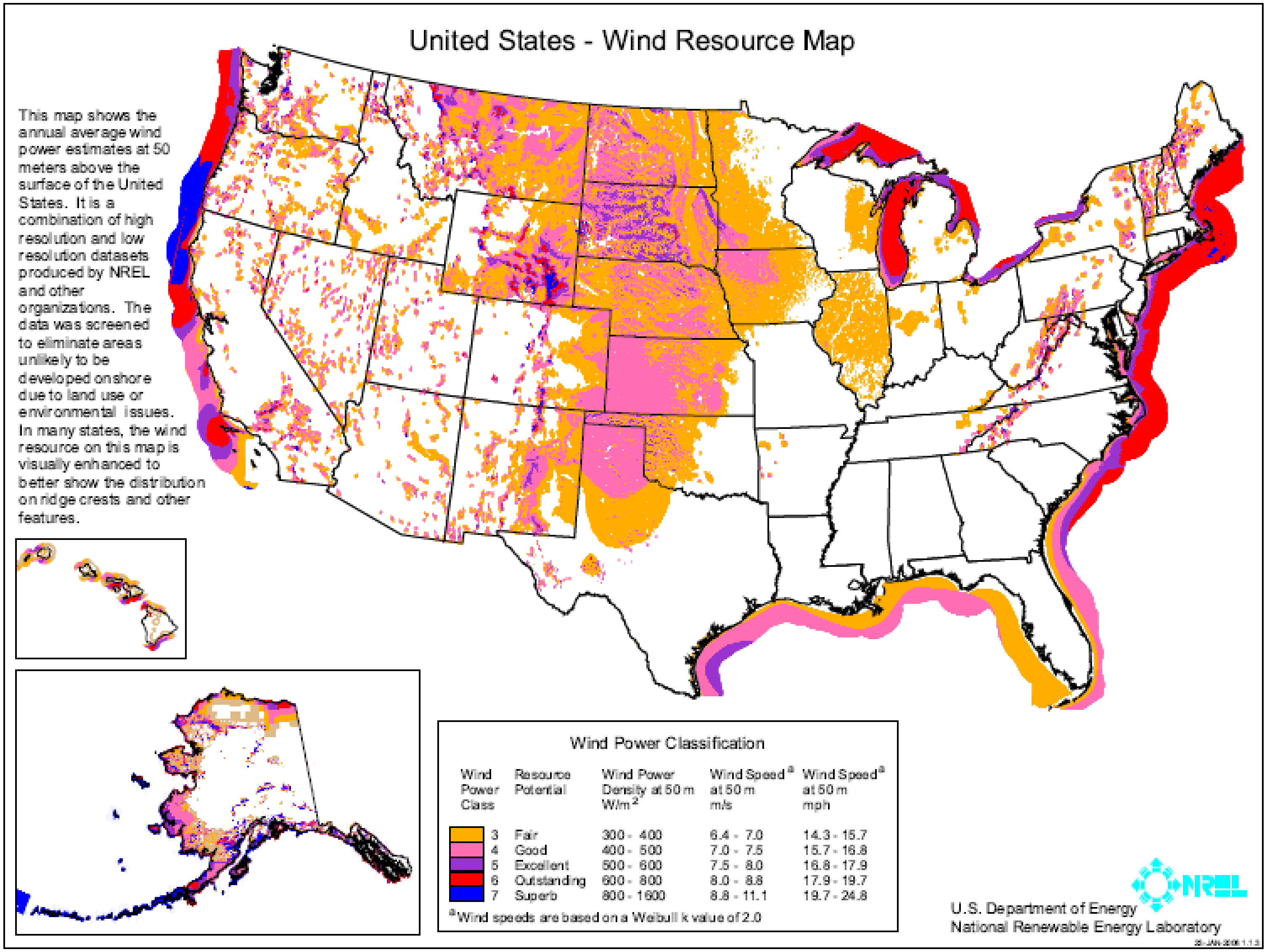
Source: BPA

Solar Intermittencies

- Seasonal, Daily, Minute Solar Power Fluctuating
- PV Inverter – Grid Interactions
- Low CF < 20%
- Inaccurate forecasting
- No storage

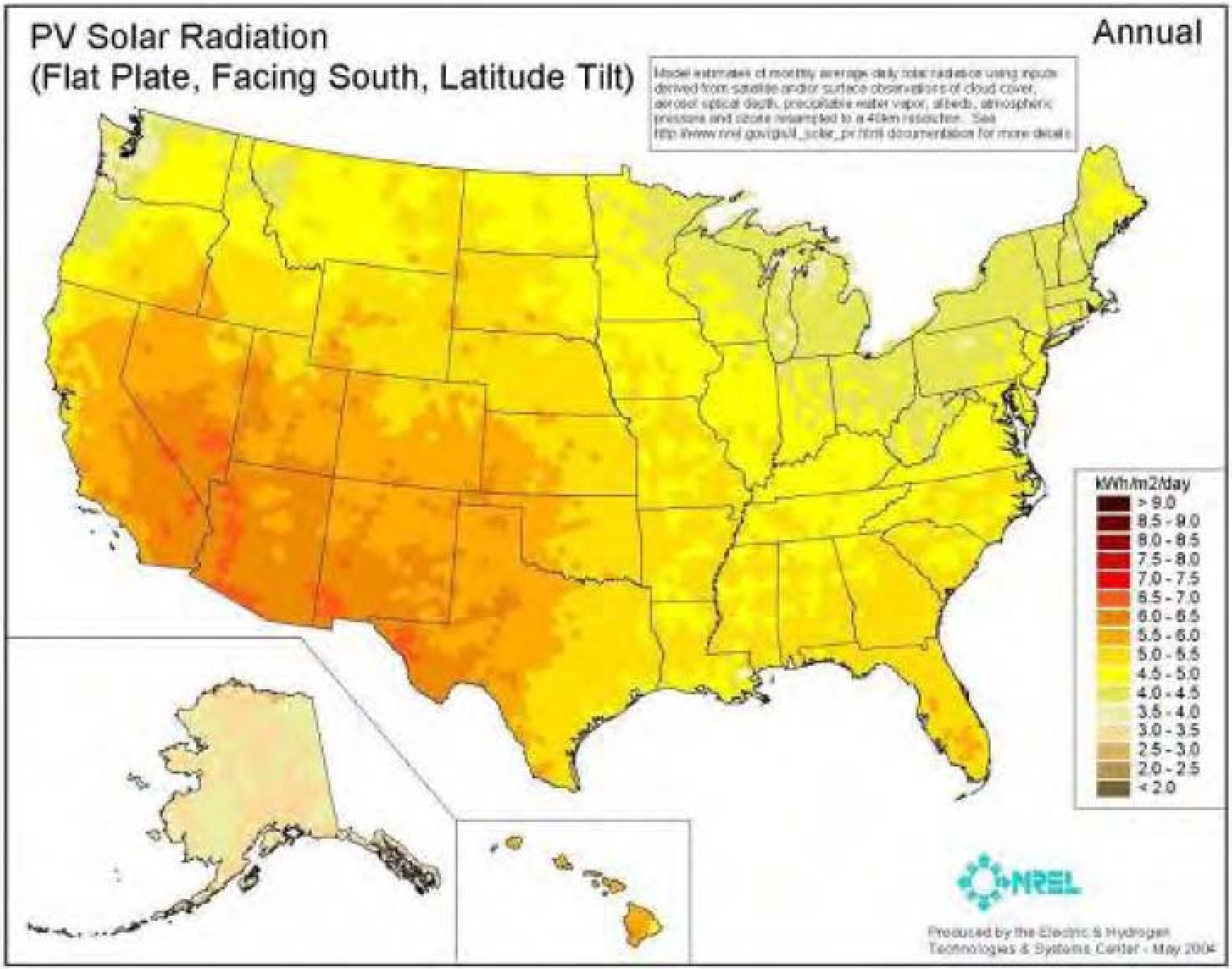


Wind Resource Map



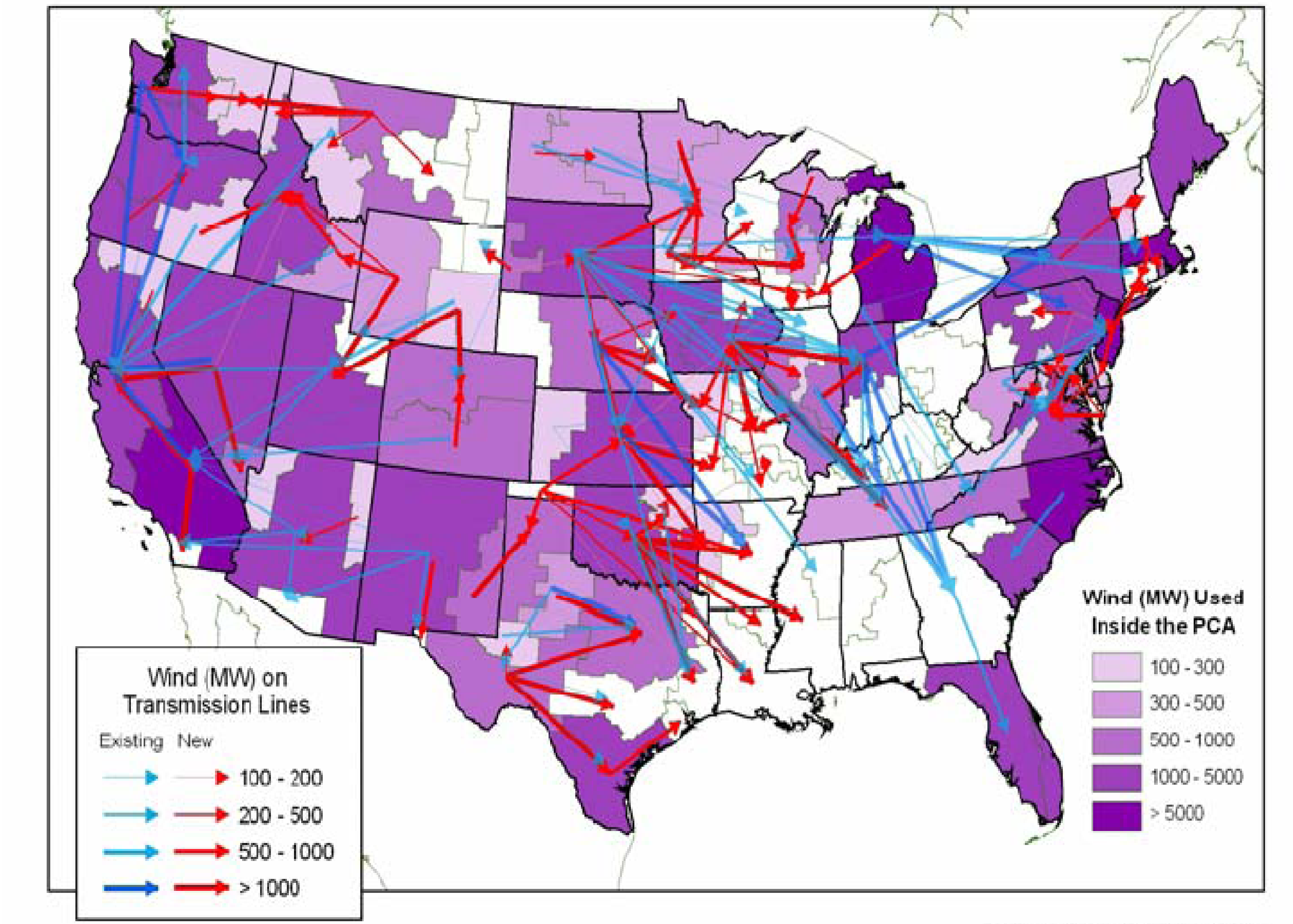
Source: DOE

Solar Resource Map



Source: DOE

Energy Policy:
DOE/NREL/AWEA Vision Report Sneak Peek



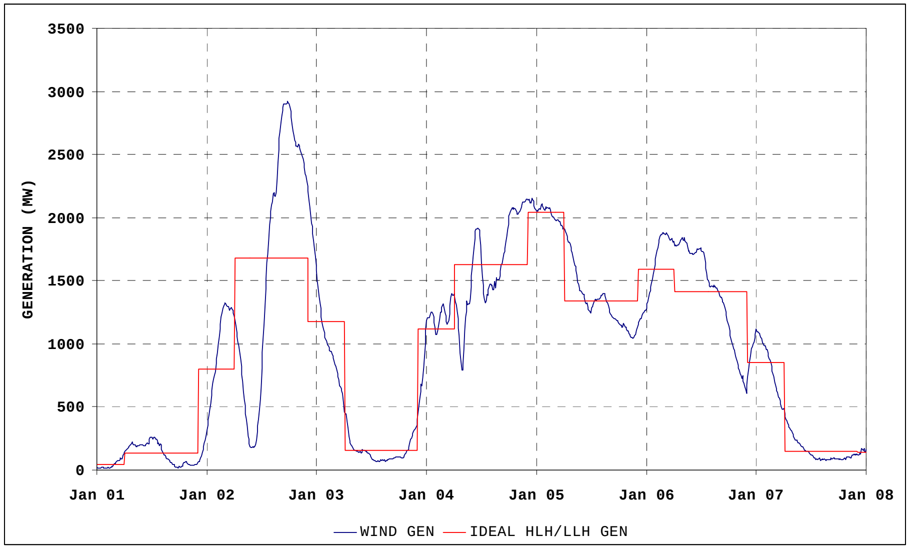
Source:
SPP/Quanta

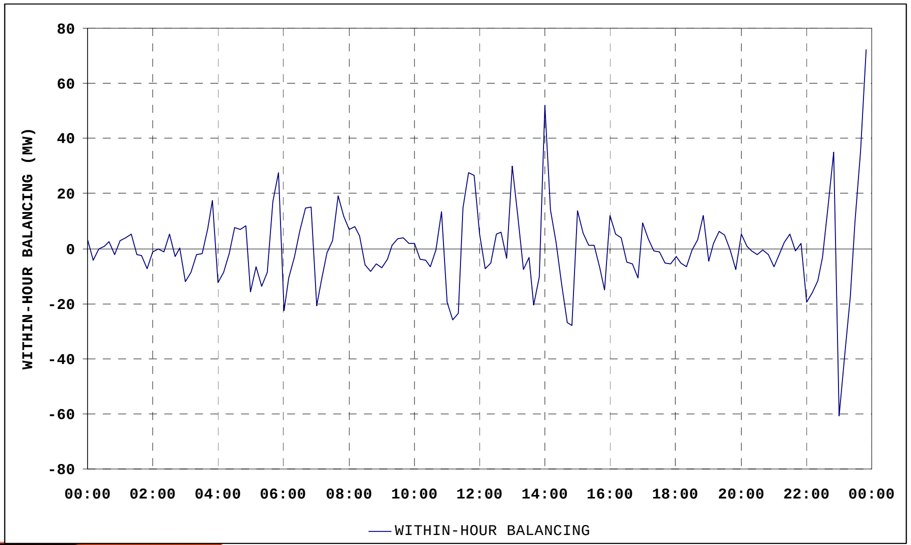
Planning for Large-scale Renewable Power

- Adequate transmission infrastructure required
- Increased effort in system planning due to intermittent nature: Grid control with suddenly lost wind power
  - Avoid overloads and stability problems
  - What is (N-1) with large wind penetration?
- Voltage support
  Local and system-wide FACTS
- Generator balancing & regulation
- Low-Voltage Ride-Through (LVRT) Requirements

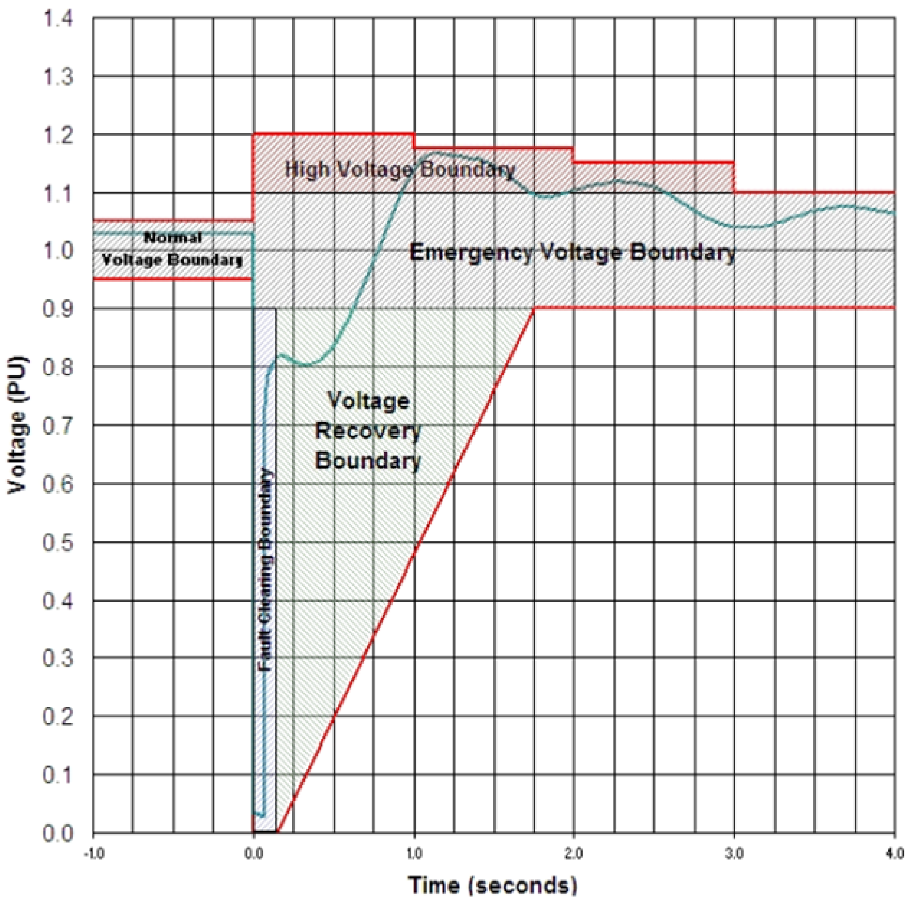
Wind Generation – Requirements

Comparison with Traditional, Dispatchable Resource





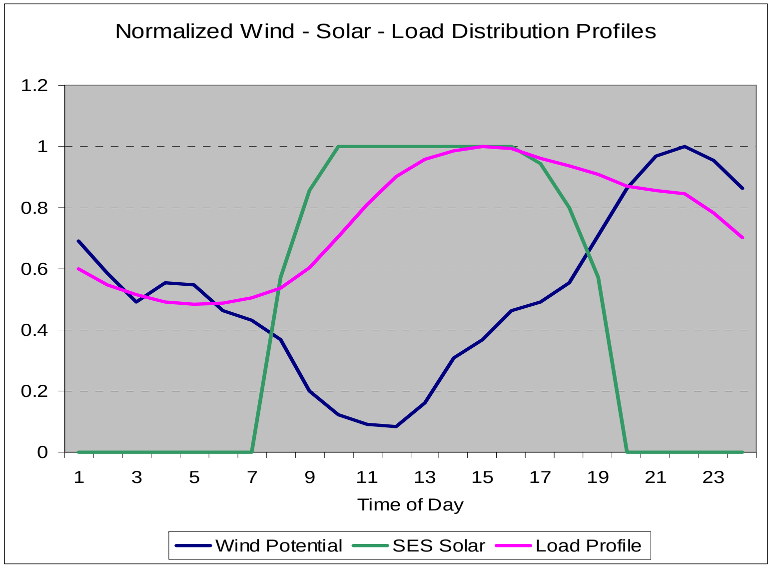
Voltage Ride-Through (FERC Standard)

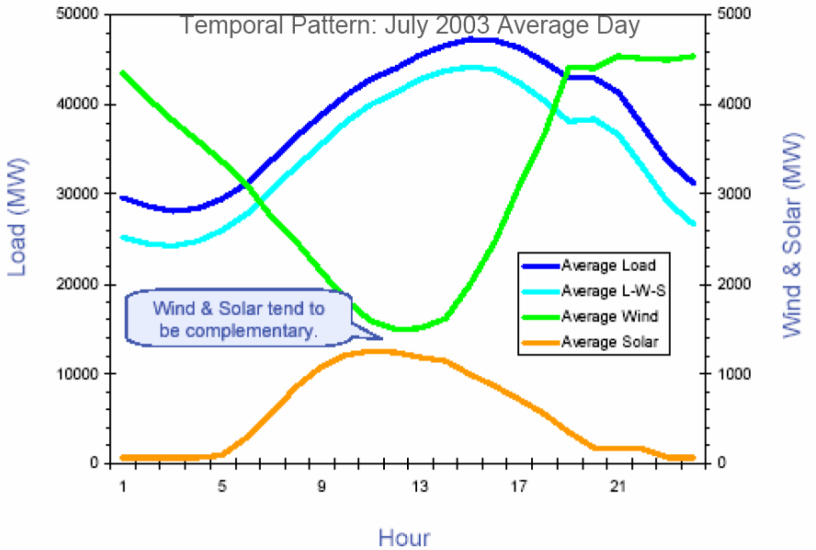


Planning for Large-scale Renewable Power

- Capacity management with reserve power for large renewable penetration
- Conventional spinning reserve insufficient for large power swings
- How to manage must-run wind?
  - Large base-load units (costs plus fuel consumption and emissions)
  - Match with other renewable sources (solar, geothermal bio-mass, etc.)
  - Add Storage
- Environmental and land issues

Complimentary Renewable Portfolio

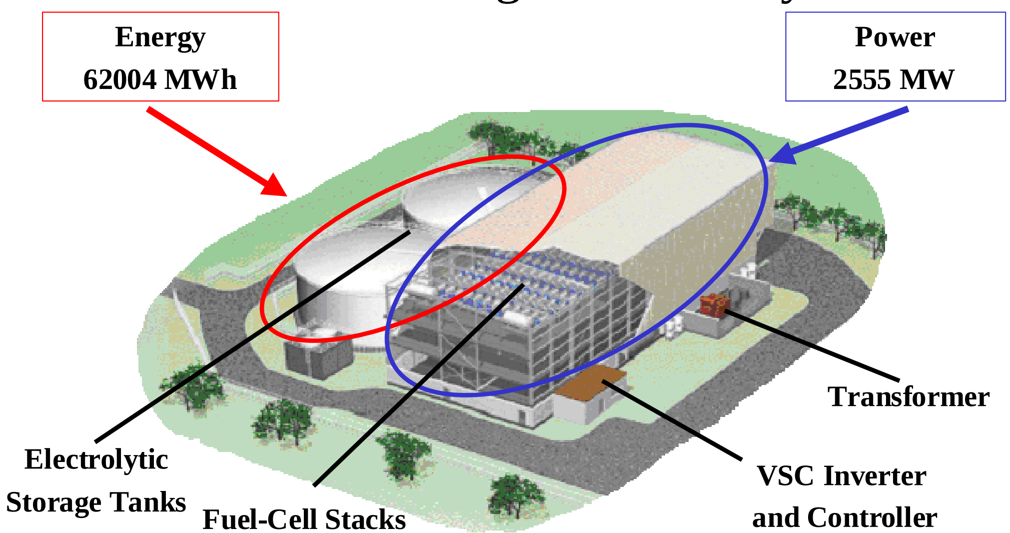




Planning for Large-scale Renewable Power

- Energy Storage
  - Short-term balancing, LVRT and Power Quality: 0.1 - 10 min
  - Regulation Services: 10 - 15 min
  - Medium-term peak shaving and load balancing: 1 – 2 hours

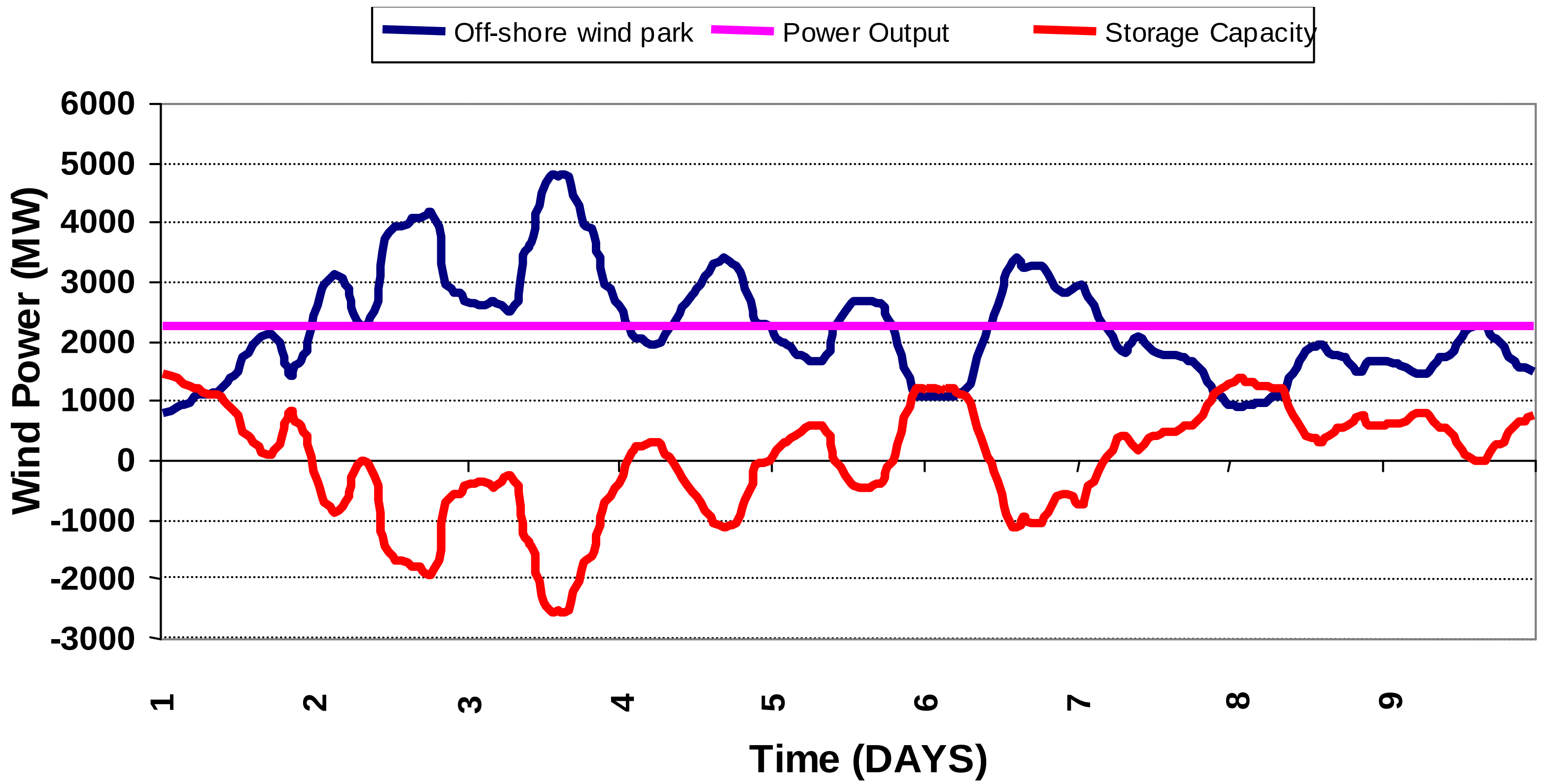
Dimensioning Flow-battery



Surface of Battery Plant for Wind Park (6000 MW):

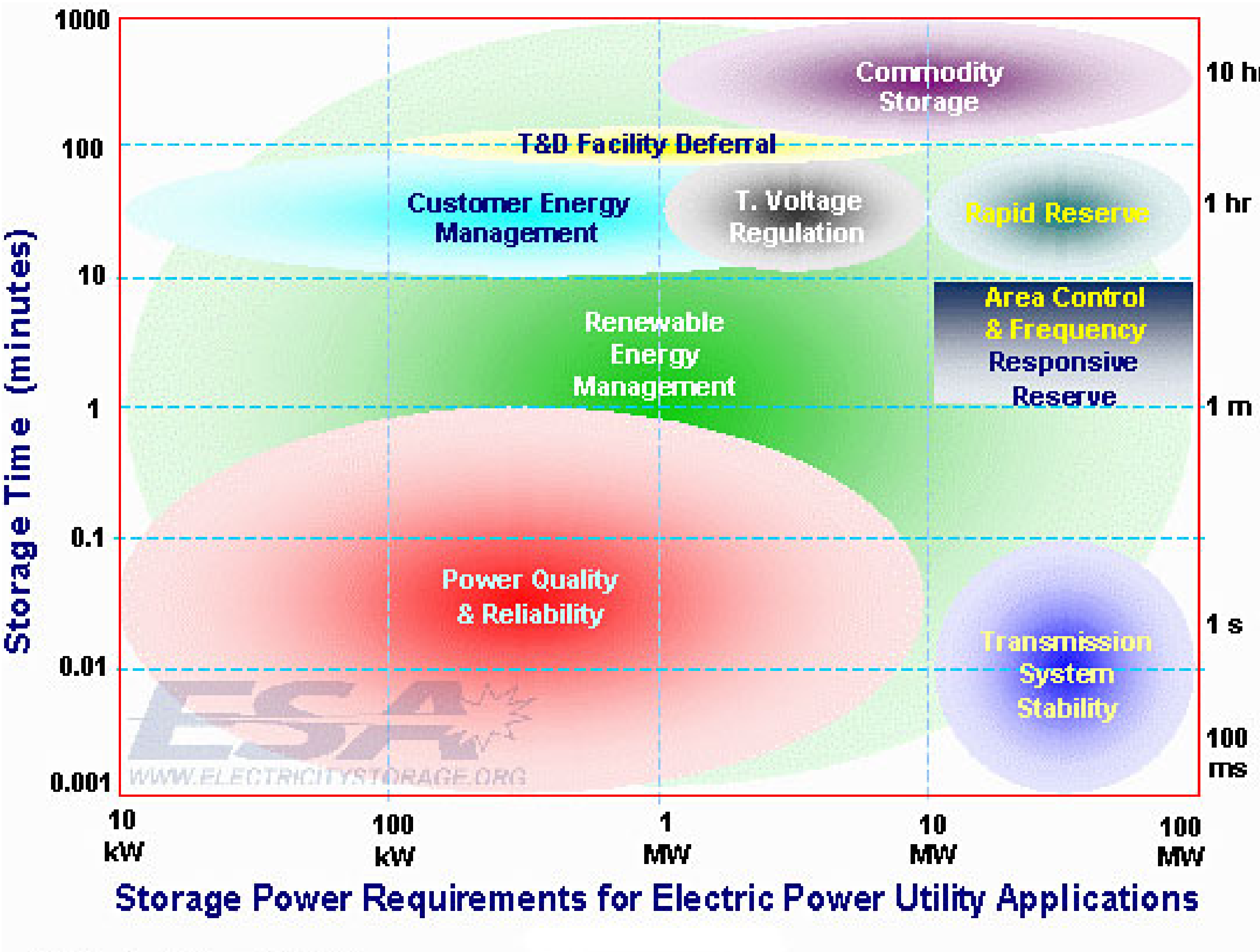
• 792.000 m2 (e.g 990 x 800 m)

Energy Storage for 6 GW Wind Farm



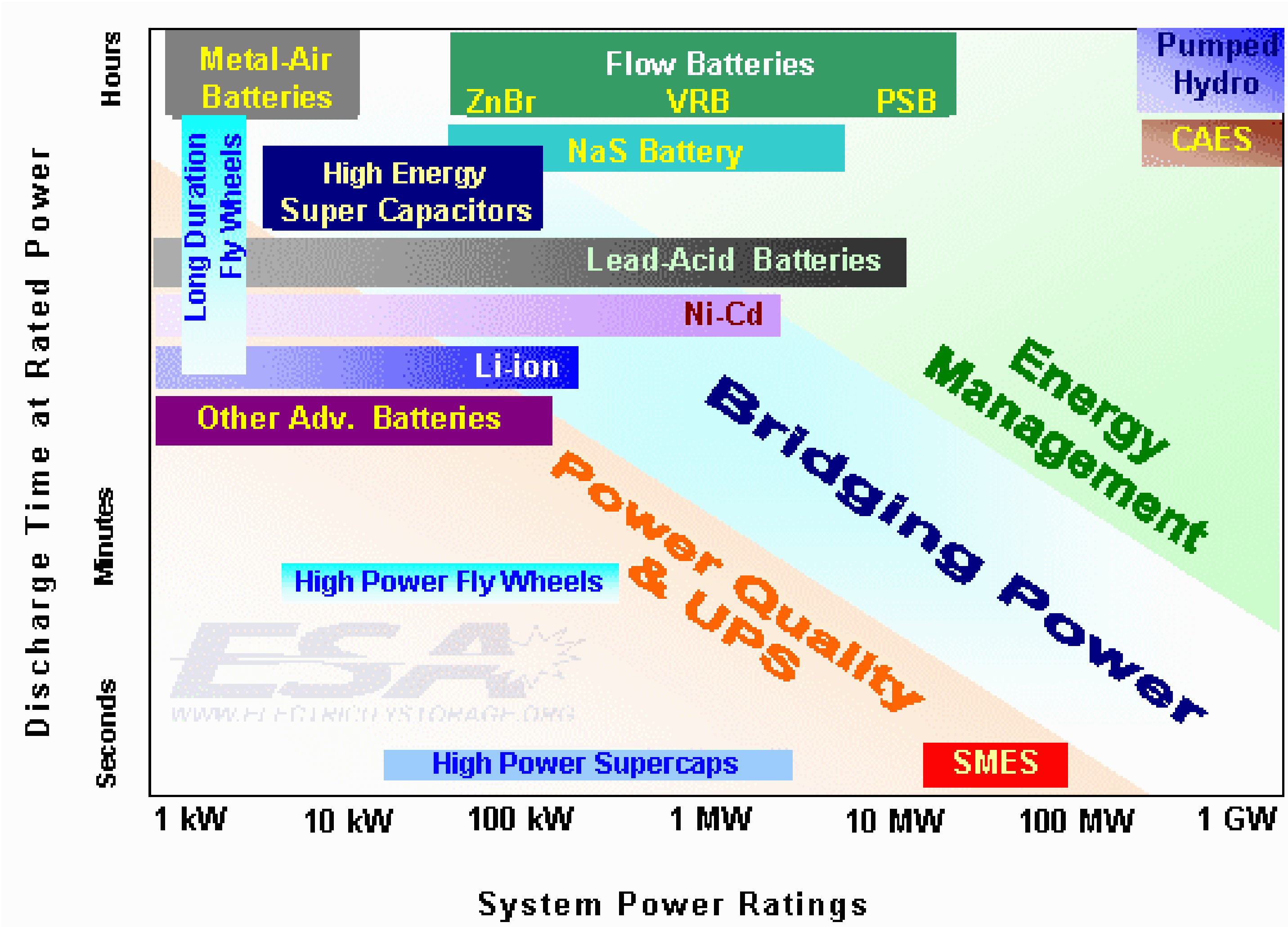
- Possible savings of 250 M€ - 550 M€ network upgrades if storage is included
- Requires 2,5 GW and 62 GWh storage for 6 GW wind farm

Storage Characteristics and Technologies



Data from Sandia Report 2002-1314

Storage Characteristics and Technologies



Planning for Large-scale Renewable Power

Key Storage Technology for Renewable Integration	Development Status and Application
Batteries	Lead-acid batteries are commercially available and widely used. Research and Development is ongoing for advanced batteries.
Flywheels	Flywheels are commercially available as fast ramping regulation services and power quality applications. Significant research is also underway to develop new, larger flywheel products.
Superconducting Magnetic Energy Storage (SMES)	Superconducting magnetic energy storage is commercially available using superconductors in liquid helium. Superconductors in liquid nitrogen are in the development stage, and are mainly used for power quality applications in 1 – 5 second range.
Pump Hydro Storage	Pump storage are the key resource for large scale power balancing and peak-power saving with large renewable energy penetration levels. These facilities are well utilized all over the world to the 300 MW / 4 – 6 hour range.
Compressed Air Storage Systems (CAES)	CAES used in several large-scale storage applications are commercially available since the 1990s. Renewed interests at the 100 MW / 4 hour range are currently underway to replace pumped hydro schemes where they are not feasible.

Distributed Storage: Plug-in Hybrid Cars (PHEV)

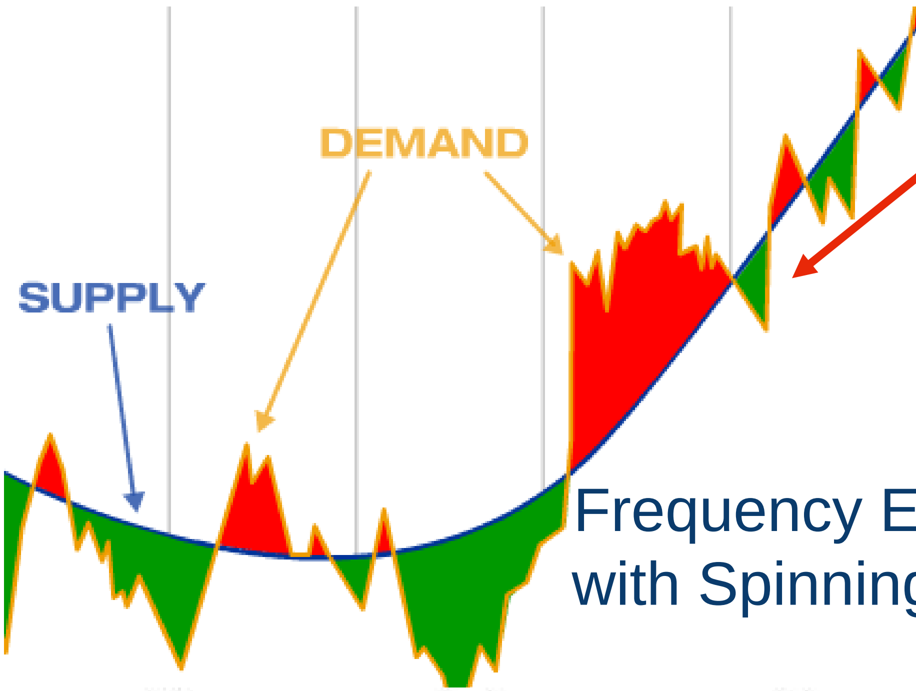
- High fuel efficiency (> 100 MPG)
- Distributed Storage for Renewable – Load Power Balancing
- 600 GWh DESR potential from 10% of 200 million US passenger cars
- Linking different fuel options and energy transport mediums

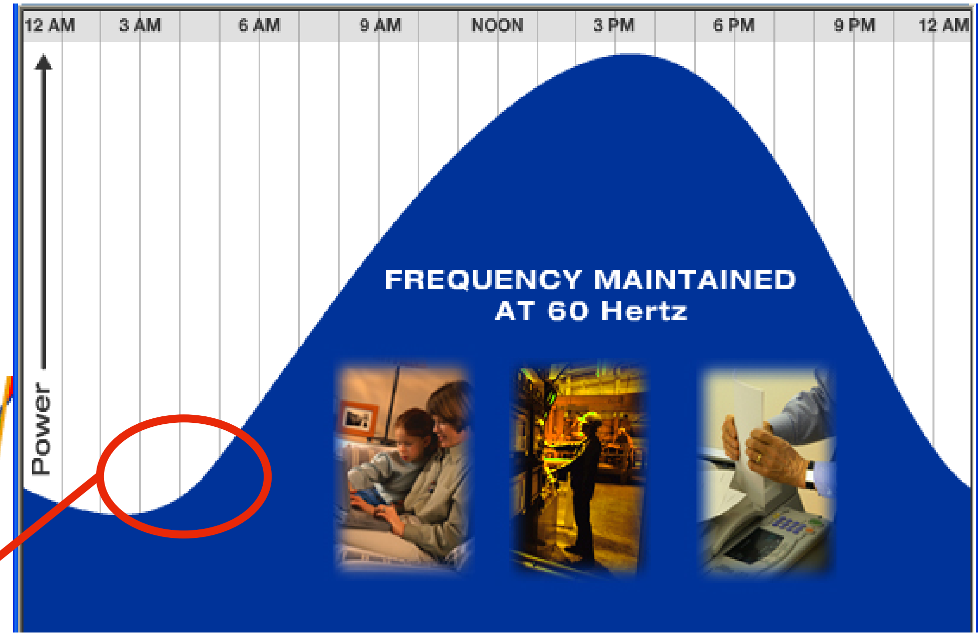
Impact on electrical grid – energy management: charging stations; peak loading; pricing signals, monitoring and control; etc.

SMART GRIDS

Flywheel Plants for Regulation Services

Short-term (1 – 15 min) Supply and Demand Curve





Daily Supply and Demand Curve

Frequency Excursions with Spinning Reserve

$$E = (I\omega^2)/2 \quad = \quad (mr^2\omega^2)/2 \quad = \quad (m\,v^2)/2$$

Source:- Beacon Power

Case Studies

Wind Integration: Some Relevant Experiences

The success of the large wind projects depends on new and upgraded high voltage transmission lines and adequate generation and load management

- ERCOT Disturbance with wind dropped from 1,700 MW to 300 MW, combined with load increase
- System operators curtailed 1,100 MW interruptible power (2 levels) within 10 minutes
- Industrial customers restored in 90 minutes
    - **Source: ERCOT, January 2008**

- German/Denmark experience shows hourly power swings of 20%
- 10% of time the hourly output varies between 5% and 20%
- Windless Days don't correspond to peak days (so far) – 35% of wind capacity is typical
    - **Source: British Wind Energy Association, September 2005**

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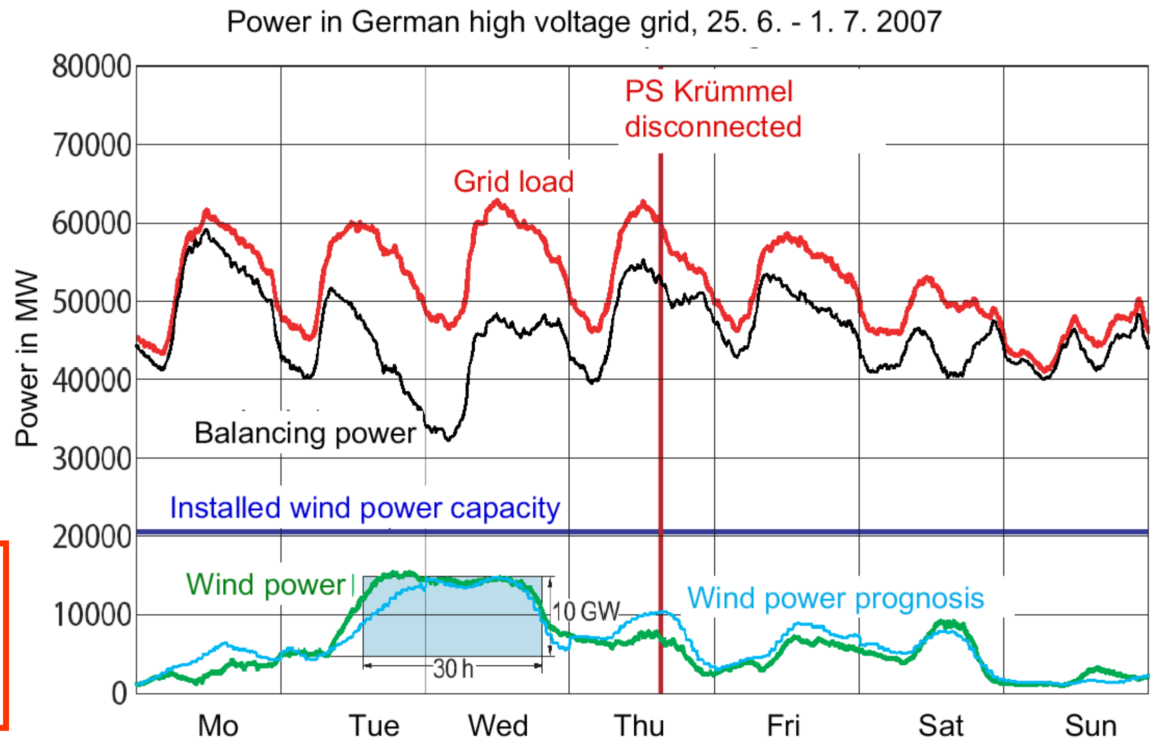
Case Study: Wind Energy Surge, Germany, June 2006

- 10 GW surge for 30 hours
- Transformer near nuclear plant caught fire, causing the plant shutdown
- Large wind penetration affects (N-1)

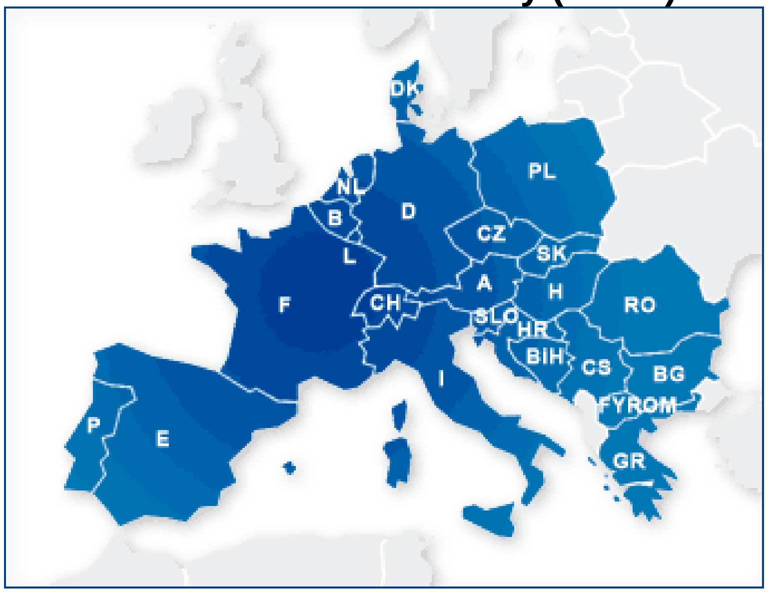
Balancing power =
Grid load - Wind power



Source: W. Leonhard, University of Braunschweig

Nov ’06 Disturbance in Europe: UCTE Report

Union for the Co-ordination of Transmission of Electricity (UCTE)



Association of transmission system operators (TSOs)

- 23 countries, 450 M people
- 140 000 miles of 400kV & 220kV

- The most severe disturbance in the history of UCTE considering number of TSOs involved
  - 23 countries and 15 M people
- Planned line outage (380kV double circuit) initiated line overloads and cascading line tripping and system separation
  - Coupling of the busburs resulted in tripping of the already overloaded line

Nov '06 Disturbance: Preconditions

- Scheduled maintenance on several transmission lines
- 15,000 MW of wind generation, North Europe and Spain
  - Large power transfer from Germany to the Netherlands and Poland due to strong, unpredicted winds
- No exchange program reduction possible after 8 AM due to auction rules

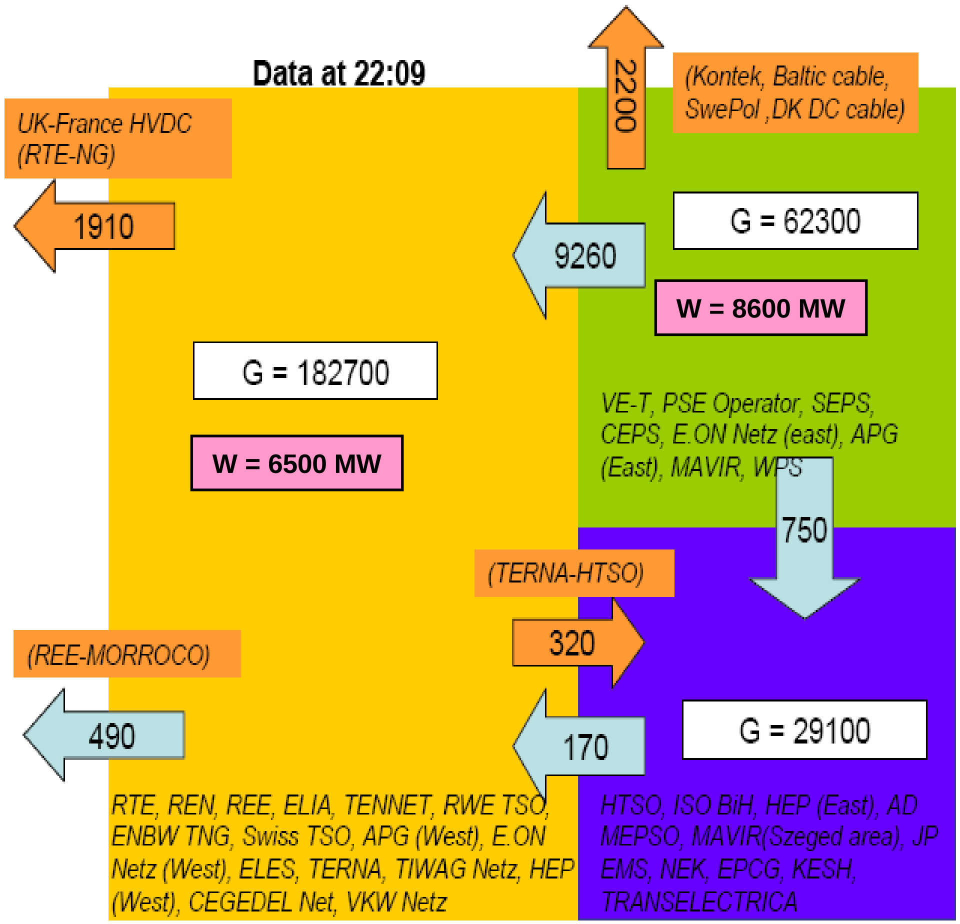
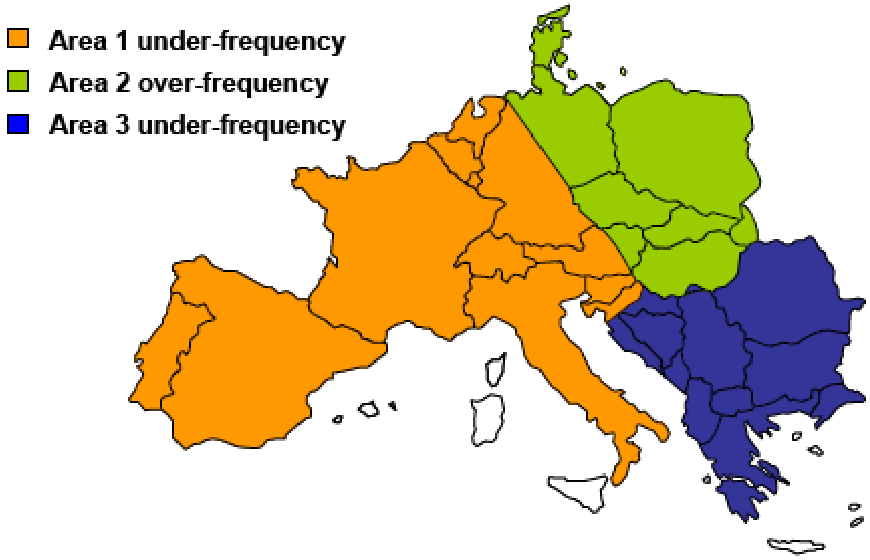


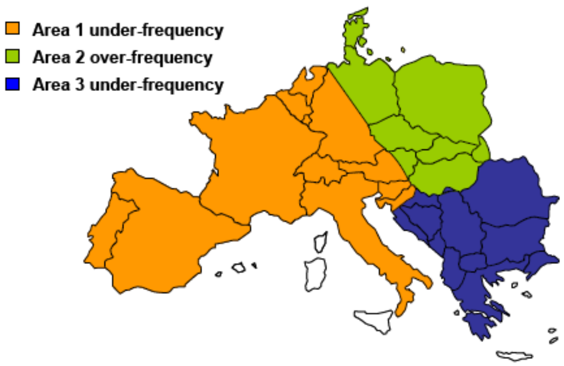
Figure 1: Generation and power flows between the 3 areas just before splitting 4 November 22:09

Nov ’06 Disturbance: Root Causes $ Critical Factors

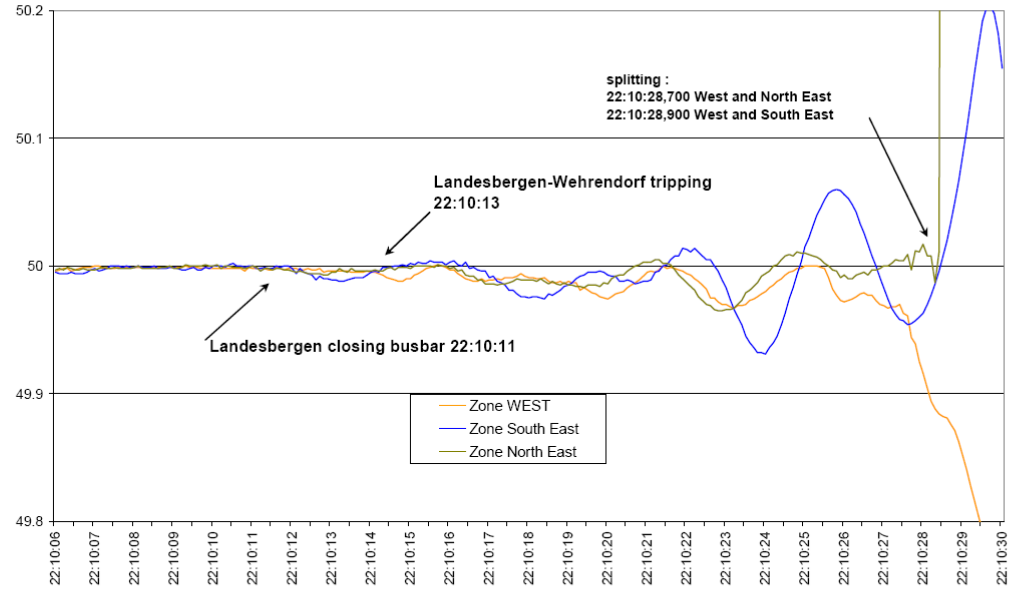
- N-1 was not fulfilled as wind generation was not adequately predicted
  - Large wind storms increased production in Northern Germany
- Inappropriate inter-TSO coordination and training
  - Changed time of the planned line outage, new conditions not checked
  - Uncoordinated protection settings on both sides of the critical line
- Uncoordinated operation of wind generators
- Coordination of restoration



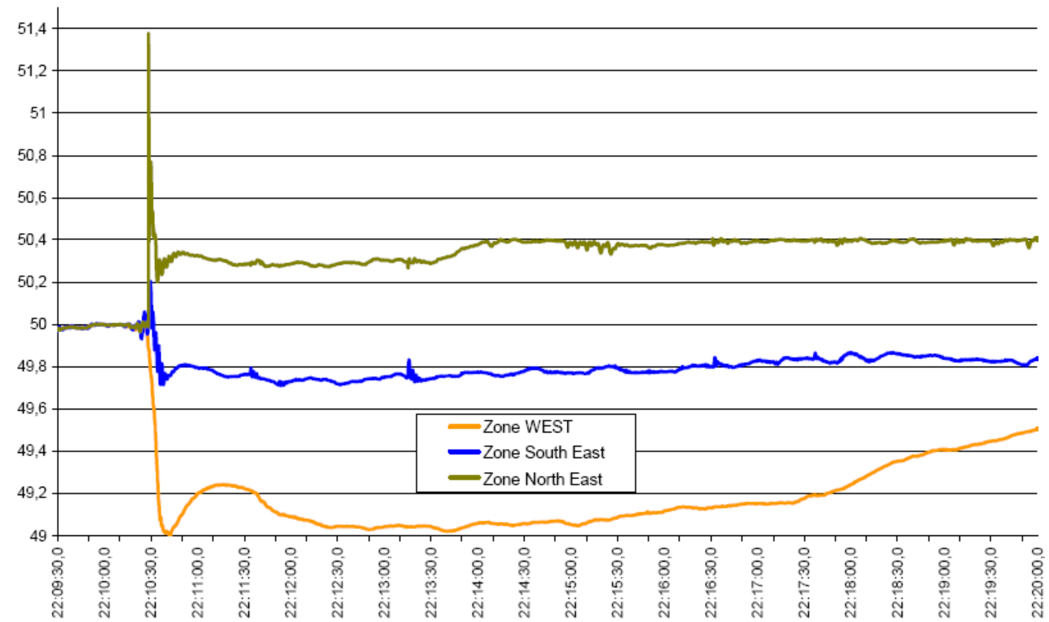
Example: Nov ’06 Disturbance, Europe



Before separation



After separation



Impact of Wind on Disturbance Propagation

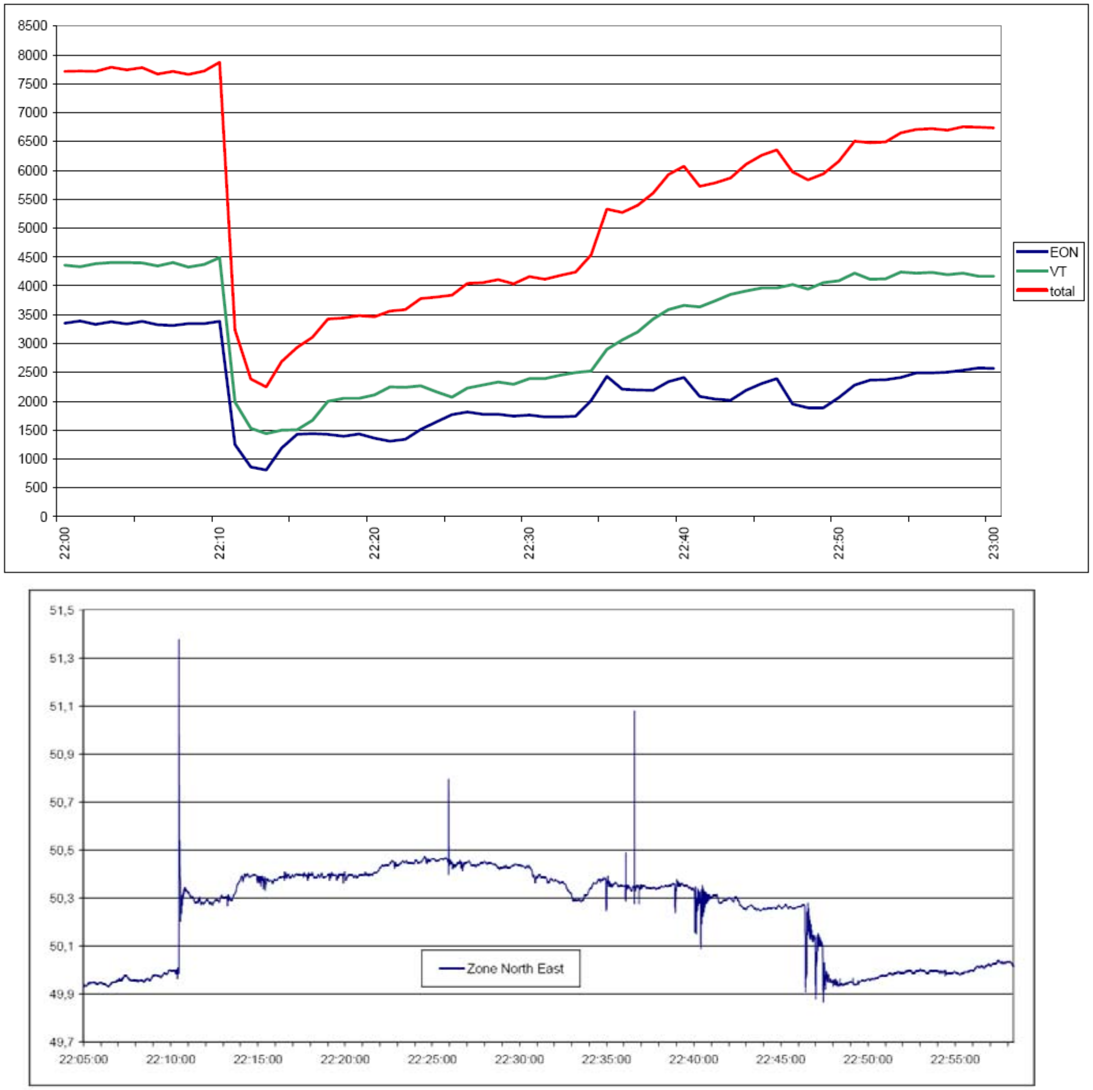
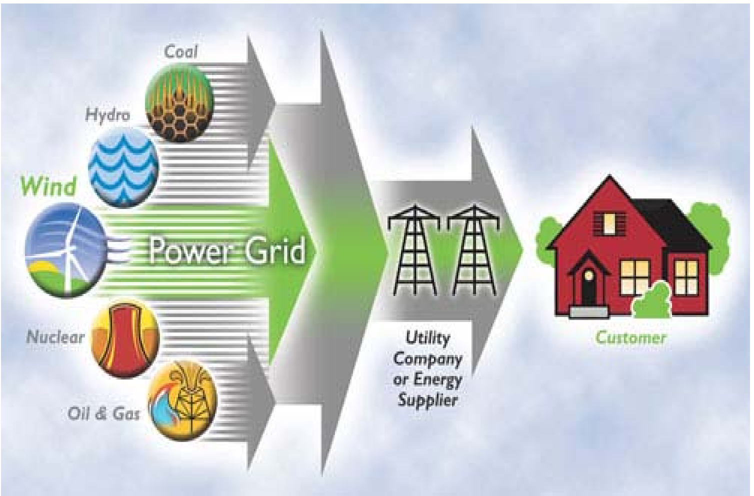


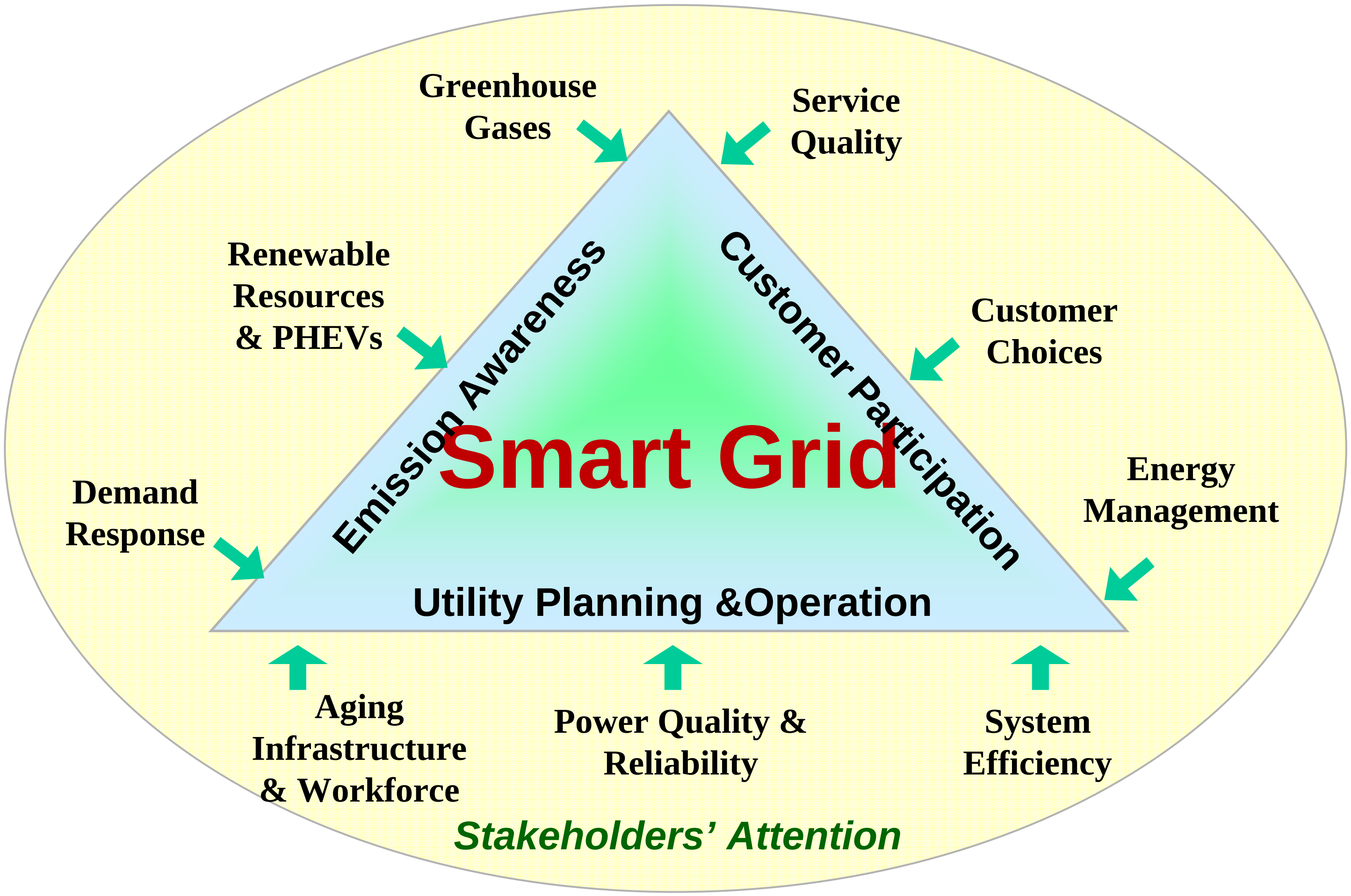
Figure 14: Frequency in area 2 (22:00 – 23:00)

- Windmills automatically connected causing frequency increase and overloads
- System was very close to another breakdown

Smart Grid


Coal
Hydro
Wind
Power Grid
Nuclear
Oil & Gas
Utility Company or Energy Supplier
Customer

Business Drivers



Consider a wider definition of value beyond financial performance, asset life, reliability, that includes customer and societal benefits

Smart Grid for Generation Resources

- How do we accommodate energy from different fuel sources and storage technologies?
- How do we optimize generation portfolios with alternative resources to promote green energy?
- How do we cluster various renewable generation and energy storage technologies to improve reliability, stability, and efficiency?
- How do we monitor and manage emissions for all generations?
- How do we strengthen transmission network to allow interconnection of all possible renewable generations?
- How do we encourage regional generation adequacy to optimize transmission corridor flows?

Approach to Large-scale Renewable Integration

Generation Mix

- Hybrid Energy Mix
- Complementary Gen.
- Advanced Power Electronics
- Generation with independe regulation.
- Larger control areas
- Fast ramping
- Regulation capability

Advanced Transmission

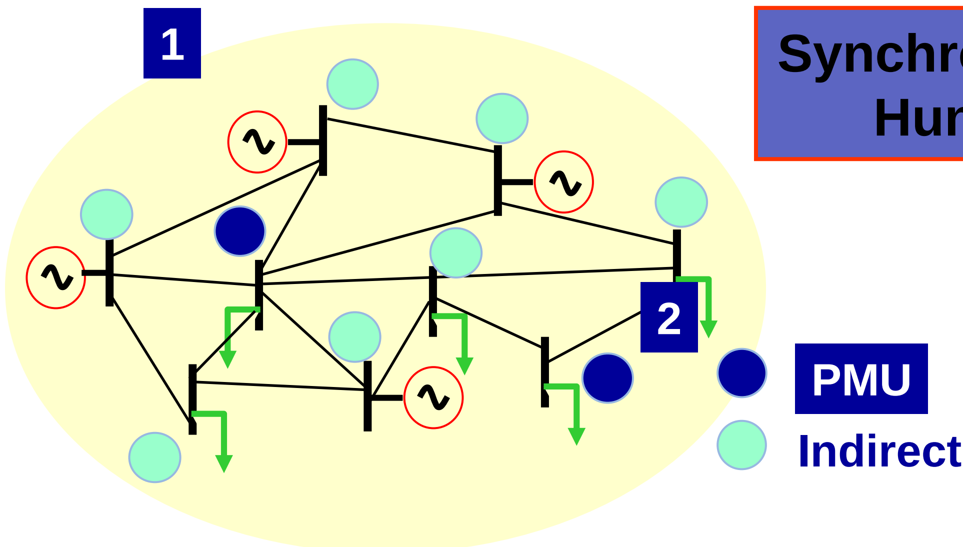
- WAMPAC
- FACTS and HVDC
- Energy Storage
- Capacity Credits
- Renewable Di
  agement
- Voltage Support & LVRT
- Ancillary Services
  - Frequency Regulation
  - Control Error
  - Spinning reserves
- Strong interconnections

Demand Response

- Wind forecasting
- Off-peak loading
- Gen. - load match
- Price sensitive load
- uency Response
- onsive to Wind
- Distributed Storage
  - PHEV
  - DES

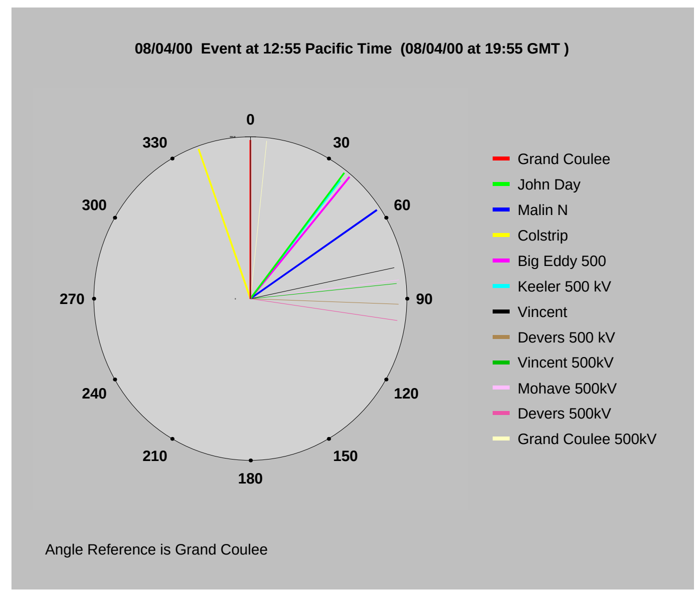
Smart Grid for Renewable

Timing the Power Grid? Why is it Useful?

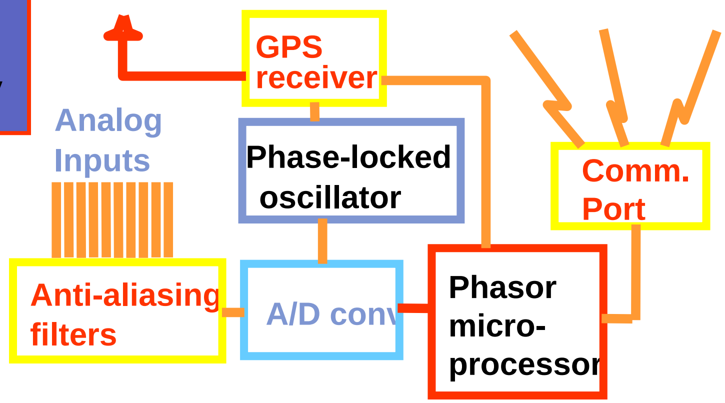


Synchronizing Measurements Hundreds Miles Apart

Grid Visibility and Situational Awareness



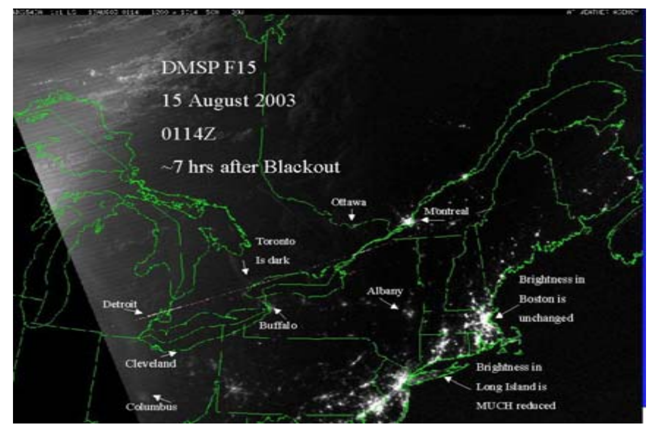
Proven HW Technology



Transmission Smart Grid: Key Benefit Areas

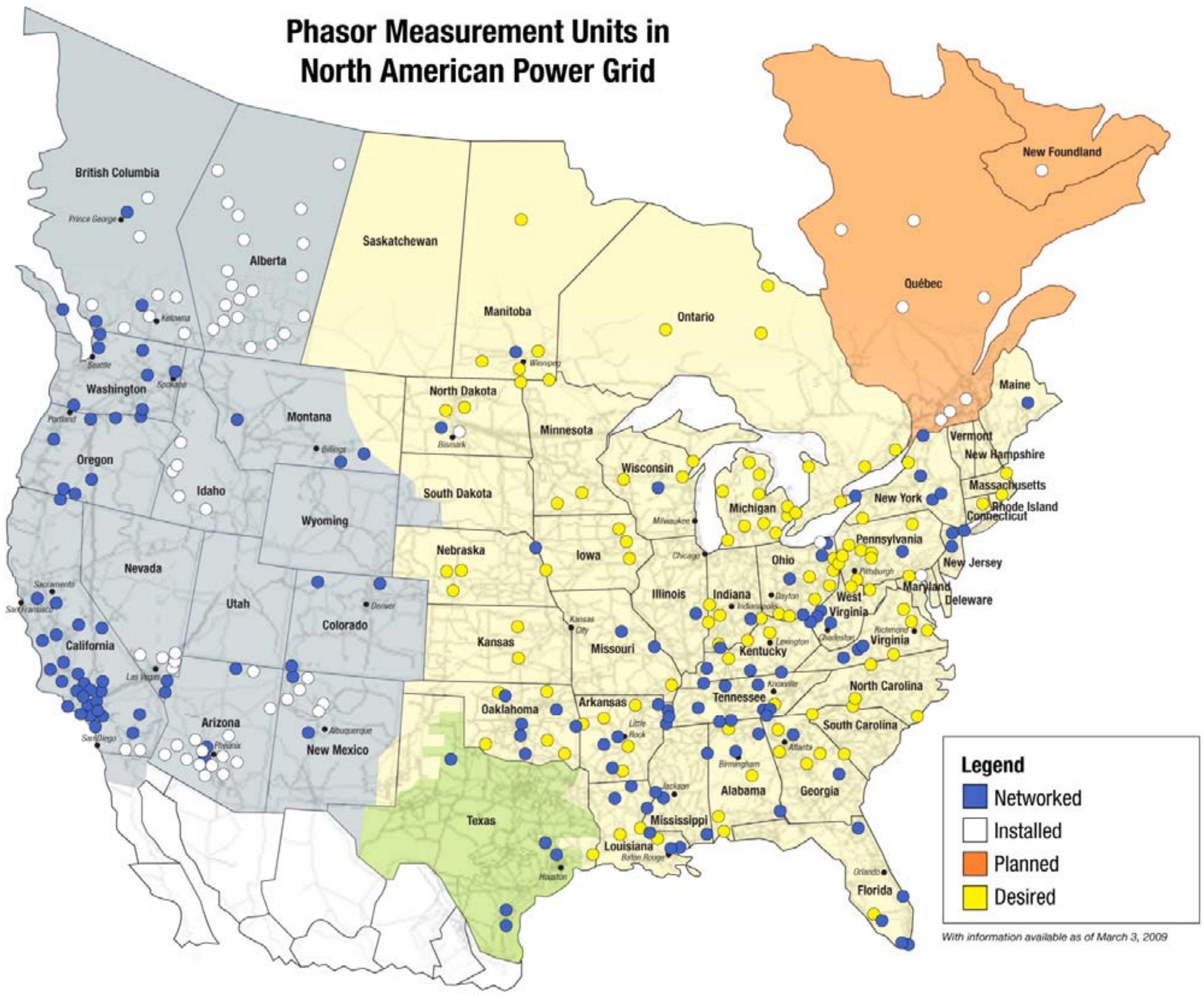
A MUST for Wide Area Monitoring, Protection, & Control

- Data Analysis and Visualization
  – Already shown significant benefits
- System Reliability: Outage/Vulnerability Reduction, System Control and Protection
  – Huge societal benefit
- System Operations and Planning, Modeling
  – Enables paradigm shift
- Market Operations: Congestion Mgmt. & LMP
  – Large potential financial benefit



Benefits of using the same infrastructure for variety of applications

PMU Installations in the US and Canada



Source: Bob Cummings, NERC

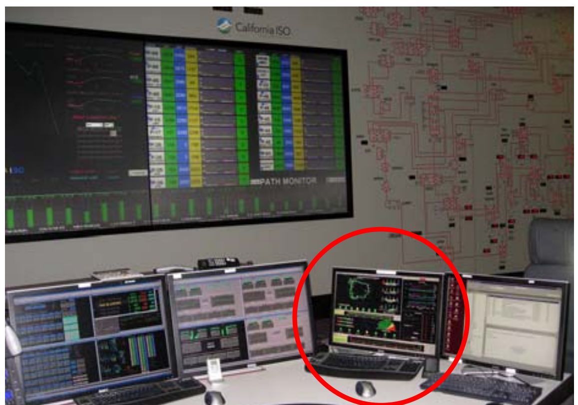
Smart Grid for Transmission: PMUs

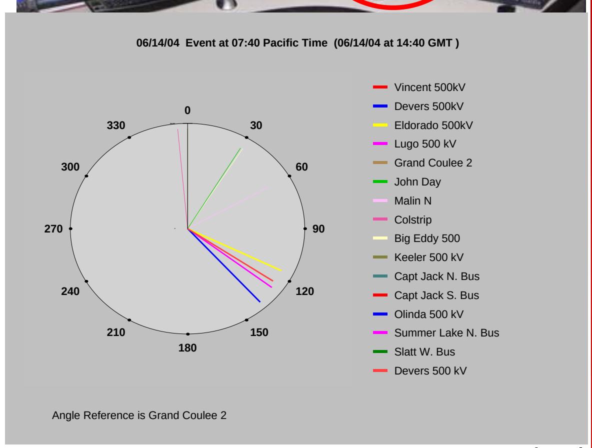
Before

First PMU

Analog Displays

Now





2014

Standard feature (relays, DFR, controllers, equip. monitors)

On all major interconnections

Improved comm. infrastructure, including control

Standard SW tools included in EMS/SCADA

2019

Higher data rates

In Distribution

Fast Adaptive Protection

Integrated in standard business and operational practices

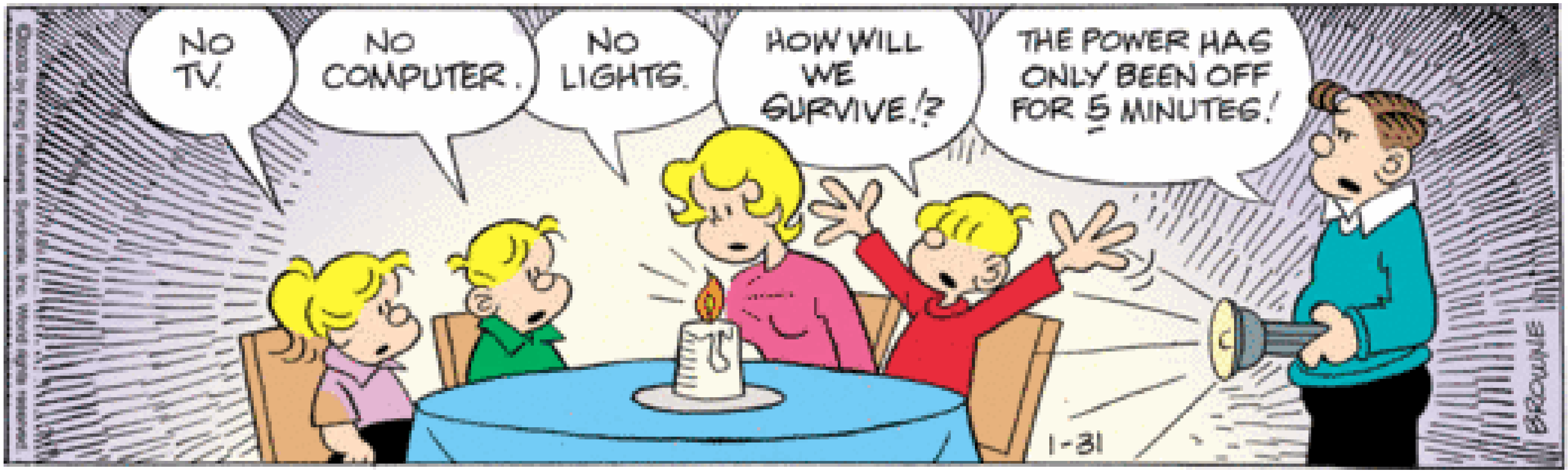
Distributed architecture, fully integrated with EMS / SCADA

SYNCHROPHASOR-RELATED GRANT OPPORTUNITIES

	DE-FOA-0000035	*DE-FOA-0000036*	*DE-FOA-000005A8*
Status	Issued 3/27/09	Notice of Intent issued 4/16/09	Notice of Intent issued 4/16/09
Focus Area	Applied Synchrophasor R&D, moving from (1) theoretical study to (2) pilot or prototype to (3) large-scale demonstration	Smart Grid Investment Grant Program – PMU deployment	1. Regional Smart Grid Demonstrations --- 2. Regional synchrophasor demonstrations. --- 3. Energy Storage
Total Funds	$2,250,000	$3.375 billion	$615 million
# Projects	1 to 3 awards	lots	1. 8-12; 2. 4-5 3. 12-19
Project Term	Up to 3 years	2 years	2 - 5 years
Funds/Project	$750,000 – 2,250,000, cost-shared, paid out by project phase	$500,000 – $20M (Smart Grid) $100,000-$5 million (PMU) DOE Cost sharing <50%	1. $5M-$40M/project 2. $15M-$20M/project 3. $200M total DOE Cost sharing <50%
Issuing entity	DOE NETL	DOE	DOE NETL
Source of Funds	DOE research budget, non-stimulus	ARRA (American Recovery and Reinvestment Act), stimulus	ARRA, stimulus
Application Due date	5/27/09, 8pm	Comments on NOI due by May 6	Comments on NOI due by May 6

Conclusions

- Renewable energy, the fastest growing generating source
- System infrastructure reinforcement and planning required
- Solutions to higher penetration levels
  - Balanced generation portfolio
  - Energy Storage
  - Implementing FACTS and HVDC
- Complexity requires Smart Grid
  - Transmission: Wide Area Monitoring, Protection, and Control



Thank You!

Questions and Discussion?

dnovosel@quanta-technology.com