



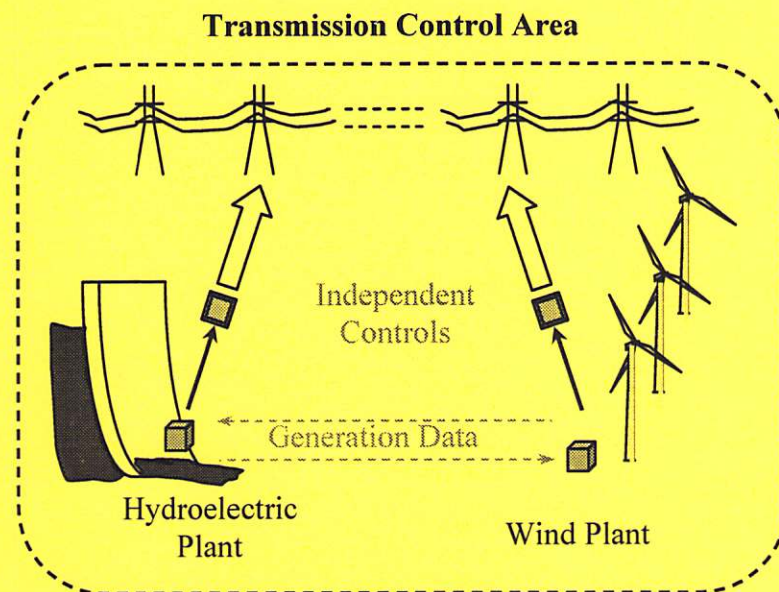
INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the
Research and Development of Wind Turbine Systems
ANNEX XI

41th IEA Topical Expert Meeting

Integration of Wind and Hydropower Systems

Portland, USA, November 2003
Organised by: NREL



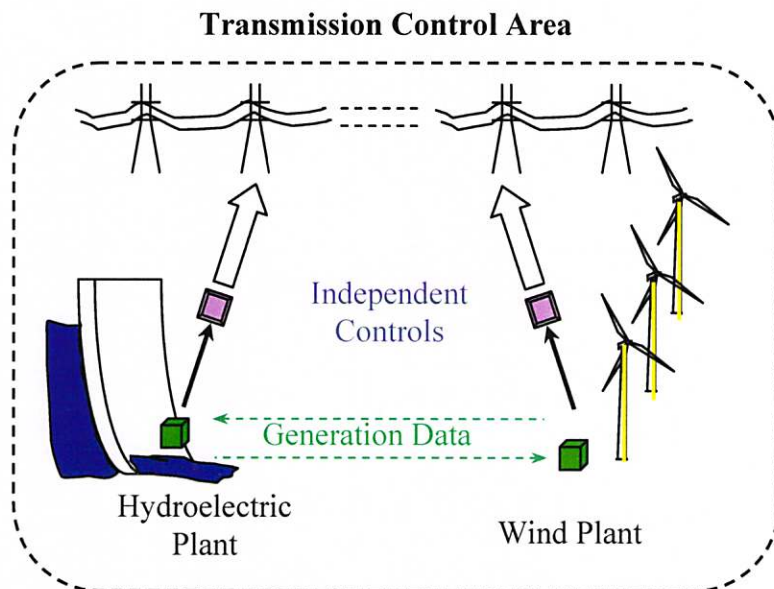


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Copies of this document can be obtained from:
Sven-Erik Thor
FOI
Aeronautics – FFA
172 90 Stockholm
Sweden
sven-erik.thor@foi.se

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IEA R&D Wind

Topical Expert Meeting #41

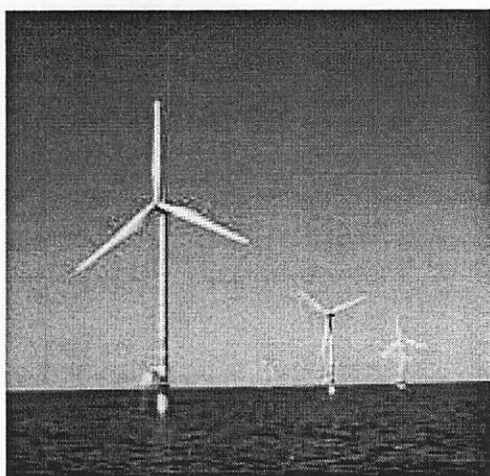
Integration of Wind and Hydropower Systems

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ANNEX XI

BASE TECHNOLOGY INFORMATION EXCHANGE



The objective of this Task is to promote wind turbine technology through cooperative activities and information exchange on R&D topics of common interest. These cooperative activities have been part of the Agreement since 1978.

The task includes two subtasks. The objective of the first subtask is to develop recommended practices for wind turbine testing and evaluation by assembling an Experts Group for each topic needing recommended practices. For example, the Experts Group on wind speed measurements published the document titled "Wind Speed Measurement and Use of Cup Anemometry".

The objective of the second subtask is to conduct joint actions in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates Joint Actions in research areas of current interest, which requires an exchange of information. So far, Joint Actions have been initiated in *Aerodynamics of Wind Turbines*, *Wind Turbine Fatigue*, *Wind Characteristics*, *Offshore Wind Systems* and *Wind Forecasting Techniques*. Symposia and conferences have been held on designated topics in each of these areas.

OPERATING AGENT:

Sven-Erik Thor
FOI, Aeronautics – FFA
SE 172 90 Stockholm
Sweden
Telephone: +46 8 5550 4370
E-mail: trs@foi.se

In addition to Joint Action symposia, Topical Expert Meetings are arranged once or twice a year on topics decided by the IEA R&D Wind Executive Committee. One such Expert Meeting gave background information for preparing the following strategy paper "Long-Term Research and Development Needs for Wind Energy for the Time Frame 2000 to 2020". This document can be downloaded from source 1 below.

Since these activities were initiated in 1978, more than 60 volumes of proceedings have been published. In the series of Recommended Practices 11 documents were published and five of these have revised editions.

All documents produced under Task XI and published by the Operating Agent are available to citizens of member countries from the Operating Agent, and from representatives of countries participating in Task XI.

More information can be obtained from:

1. www.ieawind.org
2. www.windenergy.foi.se/IEA_Annex_XI/ieaannex.html

INTRODUCTORY NOTE

IEA TOPICAL EXPERT MEETING #41

ON

INTEGRATION OF WIND AND HYDROPOWER SYSTEMS

Brian Parsons

National Renewable Energy Laboratory

1617 Cole Boulevard

Golden, Colorado

Background

Wind power is an intermittent, variable power output technology. Because of these characteristics, wind power is typically not controlled, or dispatched, by utilities. This operational mode imposes unique challenges on integrated utility grid operations. When low amounts of wind are added to an interconnected grid system, changes to grid operations are minor or negligible. However, as wind penetration increases, operations of other generators may require modification, resulting in increased costs allocated to the added wind generation. Although these additional costs do not occur only with wind generation additions, the nature of these additional requirements associated with wind is of considerable interest. The imposed additional system costs are a function of grid characteristics and increasing wind penetration, and are not well characterized at this time. These additional system costs are becoming a prime concern because the lifecycle costs of wind generation equipment have decreased to levels competitive with conventional fossil-based generation, and are expected to create strong interest in wind power capacity additions.

The additional associated, or ancillary, costs of most concern with regard to wind are associated with voltage and frequency regulation, load-following capability, capacity reserves, and capacity scheduling. The issues for grid systems with large hydropower components are not different from those for operators of grids with other generation sources, but several features of hydropower generation are attractive when considering large amounts of wind including:

- Hydropower generators have rapid regulating response and high ramp rate capabilities, and
- Water storage reservoirs can be viewed as low cost “batteries” for potentially smoothing the variability of wind power and shifting time of energy delivery.

Where federally owned and operated hydropower capacity was developed at public expense for public good, the non-polluting and rural economic development aspects of wind are viewed as an additional public good. Employing publicly-financed hydropower to accommodate additional wind generation adds value to the hydropower resource from a societal perspective.

In concept, hydropower may be able to provide short- to medium-term buffering of wind plant power fluctuations to reduce ancillary service costs and to increase the economic value of the power delivered. Adding wind to the system may or may not help hydropower meet power and other system demands by allowing the time of water delivery to be shifted.

Hydropower flows are subject to many constraints on operations, including min/max flows, min/max ramp rates, etc. Allowable flows are dictated by multivariate optimization considering the following variables:

- Fish, wildlife, and other related environmental needs,
- Irrigation,
- Navigation,
- Flood control,
- Recreation, and
- Energy/Power demands.

Often, power needs are not high in priority and energy delivery must fit into constraints imposed by the other system needs.

The overarching question is: Can the system operating impacts imposed by wind power be reduced by changing hydropower operations within the constraints imposed by other water system needs?

There are technical, institutional, economic, and political factors that need to be considered. Engineering considerations include integrated controllability and response time of generators, the transmission systems linking the physical locations of the hydropower and wind facilities, and the characteristics of the utility electric load. In addition, the capacity of the reservoirs, and the seasonal and yearly inflow variability for normal, wet, and dry years can also be important.

Institutional factors hinge mainly on the type of control and responsibility held by a utility or operating agency. For example, a hydropower system may be run in an integrated fashion, where a central utility has responsibility to meet electric load growth. Or, a system may be operated in a more run-of-the river mode, with little seasonal or yearly storage capability, governed more by hydropower capacity, rather than energy (more water available than generators to run it through). Or, a utility may not have load growth responsibility, but will purchase supplementary power for wholesale customers if they request assistance, passing all additional costs directly to those wholesale customers in near real time. Or, power may be allocated on a project-by-project basis (rather than system basis), where there is the ability to store water over long periods, and output is more energy limited than capacity limited (water short, not limited by the number/size of generators).

Individual institutional situations are important as the context for assessing wind/hydropower integration opportunities. For example, in some cases an individual hydropower resource may be developed for the benefit of specific customers, whereas in other cases, a whole drainage system may be operated in an integrated fashion.

Economic analysis issues are mainly associated with value tradeoffs, market prices, and the ability to limit non-power producing water spills. In addition to the already discussed ancillary service cost issue, differentials in seasonal and daily power demands and prices are important. Peak and off-peak power prices can vary as much as a factor of 3 or 4, resulting in a high value of the ability to shift time of energy delivery.

Politically, hydropower and other water use allocations are often contentious. Some parties may wish to use existing hydropower allocations to support integration of wind, where there is interest in wind development for economic development reasons. Other entities may see wind as a threat to their interests, for example many utilities with federal hydropower allocations also have large investments in fuel production and other electric generating stations, which could potentially be displaced by wind generation.

Worldwide, there have been some limited-scope activities aimed at exploring the issues associated with integrated wind-hydropower operations. With results becoming available from

an increasing number of pilot studies and investigations, the value of synthesis of best practices is reaching a point where a focused assessment is now appropriate. Lessons-learned from earlier work can now be investigated for appropriateness to future planned projects.

Objectives

It is proposed to hold an expert meeting to establish an overview of existing knowledge, and experience relating to the technical issues, potential benefits, and operational challenges associated with the combined operation of wind and hydropower generation.

The results of the workshop will be:

- A general description of the technical and operational issues associated with combined wind-hydropower generation;
- Compilation of lessons-learned from existing integrated wind-hydropower operations; and
- Input to define a possible IEA future role in this field.

Means

Various methods will be employed to evaluate and review prior technical, operational, and theoretical knowledge relating to integrated wind-hydropower systems.

Case studies of existing facilities should be compiled. Lessons-learned offered by operators of such facilities should be illuminated and synthesized.

Possible system operations challenges should be discussed; transmission-system loads and dynamics should be addressed.

Potential societal, economic, and system benefits from integrating wind and hydropower systems should be identified.

Regions where future application of these integrated systems shows greatest potential should be discussed. Criteria for identifying such regions, and applicability of current knowledge to future applications in those regions should be included.

The expert meeting should be held in order to identify the primary needs of primary research objectives that could constitute an annex.

Expected Output

The output of the IEA workshop will be this identification of technical, institutional, economic, and political issues associated with integrated wind-hydro, as well as an inventory and discussion of lessons-learned from prior work around the world.

Intended Audience

The national members will invite the participants for the meeting, preferably participants with access to existing integrated wind-hydropower projects, involved with associated research, and/or wind-hydropower planning.

The audience should be researchers, engineers, and theorists working at research centers, universities, and utilities involved in wind operations and/or hydropower operations.

The Meeting will cover the following topics:

- Identification and characterization of common wind and hydropower resource areas,
- Relevant transmission, system control and operations issues,
- Benefits of integrated systems: technical, institutional, economic and others, and
- Applicability and use of lessons-learned from prior projects for prospective projects in new regions around the world.



Wind-Hydro - Present Situation and Options for the Future

IEA-Wind Hydropower Workshop
November 5,6, 2003

Frans Koch

Secretary of the Executive Committee of the IEA
Hydropower Agreement

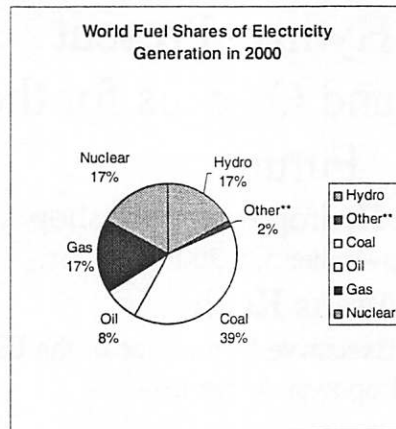


Introduction

- Present Framework Conditions
 - electricity production
 - economic & market
 - public acceptance/political
- Options for the future
- Cooperation among Implementing Agreements



Electricity Generation Today



Total Generation in 2000: 15,379 TWh of which hydropower was about 2,614 TWh and wind 28.9 TWh in 2000 and 47 TWh in 2002 (IEA countries only)



Storage Capacity of Hydropower

- Data not easily available on share of run-of-the-river hydro vs reservoir hydro. In many countries run-of-the-river is more than 50 % of total capacity
- Reservoir capacity can vary widely from country to country
- During dry years (20 % less than average rainfall) hydro intensive countries/regions are usually not able to meet demand (Brazil and Western USA in 2001, Norway in 2002)



Pumped Storage Hydro and Wind Capacity

Country	Wind Capacity GW	Pumped Storage Capacity/GWh
Germany	12.0	5.5
Spain	4.6	n.a
USA	4.7	19
Japan	0.3	19
China	0.5	5.7
Denmark	2.9	n.a



Economic Framework

- Many countries/regions have liberalized electricity markets.
- Market rules for ancillary services (storage, back-up) vary widely from jurisdiction to jurisdiction. (market mechanisms, fixed contracts)
- Coal and Natural Gas - Combined cycle are currently lowest cost technologies in North America, Hydropower in Brazil, China, India.
- Due to preponderance of steam generation (nuclear, coal, natural gas CC) electric storage capacity is in short supply in many regions. In some exceptional cases electricity has had a negative price for a few hours.
- Construction of pumped storage facilities can cost from \$ 2000 - \$ 4500 per kW of capacity, and energy efficiency is about 70 %, yet in some jurisdictions pumped storage is quite profitable.
- Due to liberalization, the cases where electricity storage is provided free of charge are becoming increasingly rare.



Public Acceptance/Political

- Large scale hydropower including large scale pumped storage is facing challenges in the area of public acceptance. A number of well-financed, well-organized organizations exist for the purpose of opposing large dams and reservoirs.
- Wind power has a very positive public image, although there may be local resistance to large wind farms.
- Public acceptance and political decisions will have a strong influence on which primary energy options are chosen by different countries.
- Wind/hydro could form a public acceptance coalition to compete with clean coal and nuclear



Options for the Future

- Cheap oil and gas could be depleted in 20 to 40 years depending on political stability and economic growth in the BRIC (Brazil, Russia, India, China) countries.
- The only feasible options for the future power sector in terms of cost and scale are clean coal, nuclear, and wind/hydro. The market share of each will depend on costs and public acceptance/political issues.
- The transportation sector might become an important end user of electricity as an energy carrier due to plug-in hybrid vehicles. This might increase demand for electricity by 50% to 100%. (Bio-ethanol would also supply the transportation sector).



Options for the Future

- “Clean coal” including carbon sequestration, and the nuclear options put a certain ceiling on the cost of electricity (perhaps 8 to 10 cents/kWh). Wind/hydro would need to be competitive at around this level.
- Public acceptance and political issues include energy security and environmental issues.
- Scale (no. of GWh produced) will be an important consideration. (It takes 2000 wind turbines of 2 MW to produce same no. of GWh as a 500 MW coal plant.)
- Like hydropower, wind power may run out of good sites



Project Level Opportunities and Constraints

- Individual reservoir hydro facilities have limits on upper and lower levels of the reservoir, often a minimum flow requirement, and a limit on maximum flows (avoid floods downstream). Water scheduling can take away a lot of flexibility.
- The transmission system is often limited.
- Hydro plants are generally designed to operate at about 70% of maximum capacity, so that there is a 30% turbine capacity that could be used in combination with wind energy.
- The amount of wind energy on a specific day may be difficult to predict, but the amount of wind energy produced during the previous day/week is known, and could be used in water scheduling for the coming day/week.




Cooperation Among Implementing Agreements

- “Joint Annexes” among two Implementing Agreements have been successfully done (Deployments Strategies for Clean Energy Vehicles) but require a bit more legal work and slightly higher management costs than conventional annexes.
- A joint “wind-hydro” annex could collect case studies of combined wind and hydro operations, analyze the experience acquired, document “good practices”, and make recommendations for the future. It could also articulate the policy advantages such as energy security, reduced energy imports, reduced GHG and other emissions.



Conclusions

- From a technical perspective, dealing with intermittent wind energy depends on - and varies strongly among - grid systems.
- From an economic perspective, intermittent wind energy has a low value in a liberalized electricity market. Storage/back-up can be bought in some markets, but comes at a price.
- From a public acceptance/political perspective, Governments may decide to support large scale wind and storage projects for energy security and environmental reasons.
- At the project level, wind and hydro can be combined, and it would be useful to share international experience about this.
- A “joint annex” could be set up to further study the issues related to combining wind and hydro.

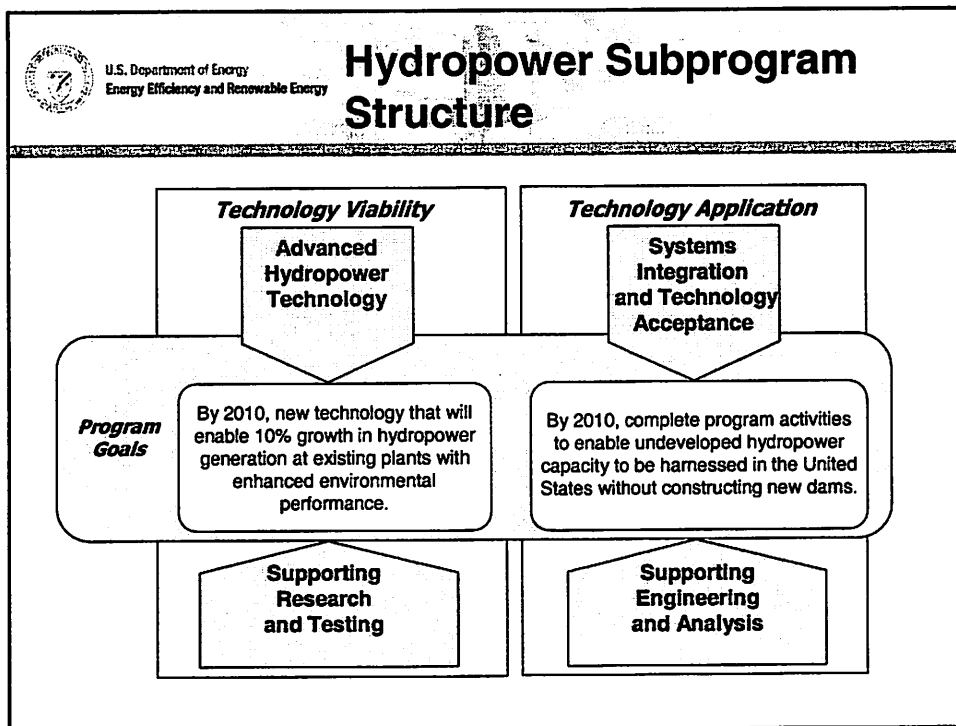


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Hydropower R&D Program Overview

Jim Ahlgrimm

Technology Manager
Wind and Hydropower Technologies Program

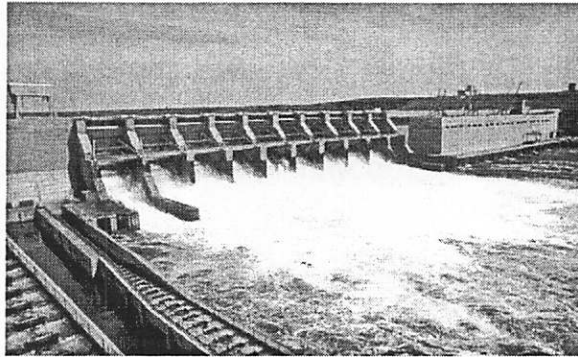




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Technology Viability Goal

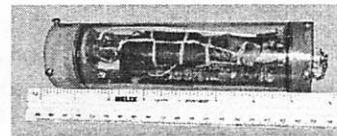
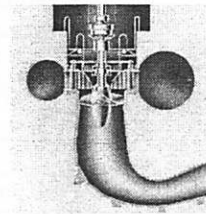
By 2010, new technology that will enable 10% growth in hydropower generation at existing plants with enhanced environmental performance.

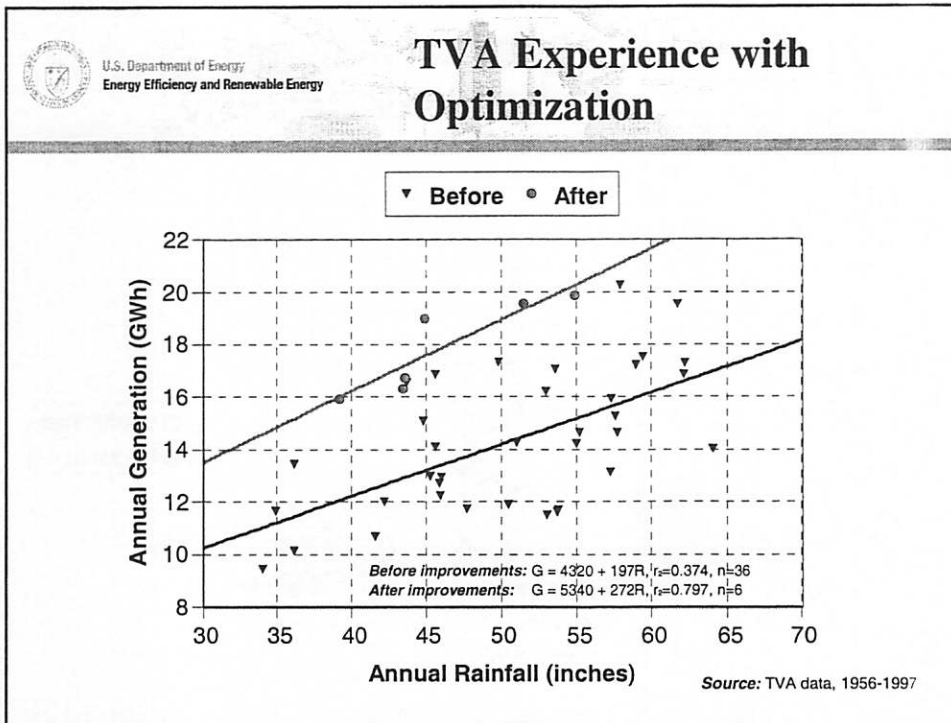


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Technology Viability Activities

- Advanced Hydropower Technology
 - Large Turbine Testing
 - Water Use/Operations Optimization
 - Improved Mitigation Practice
- Supporting Research and Testing
 - Biological Design Criteria
 - Computer and Physical Modeling
 - Instrumentation and Controls
 - Environmental Analysis

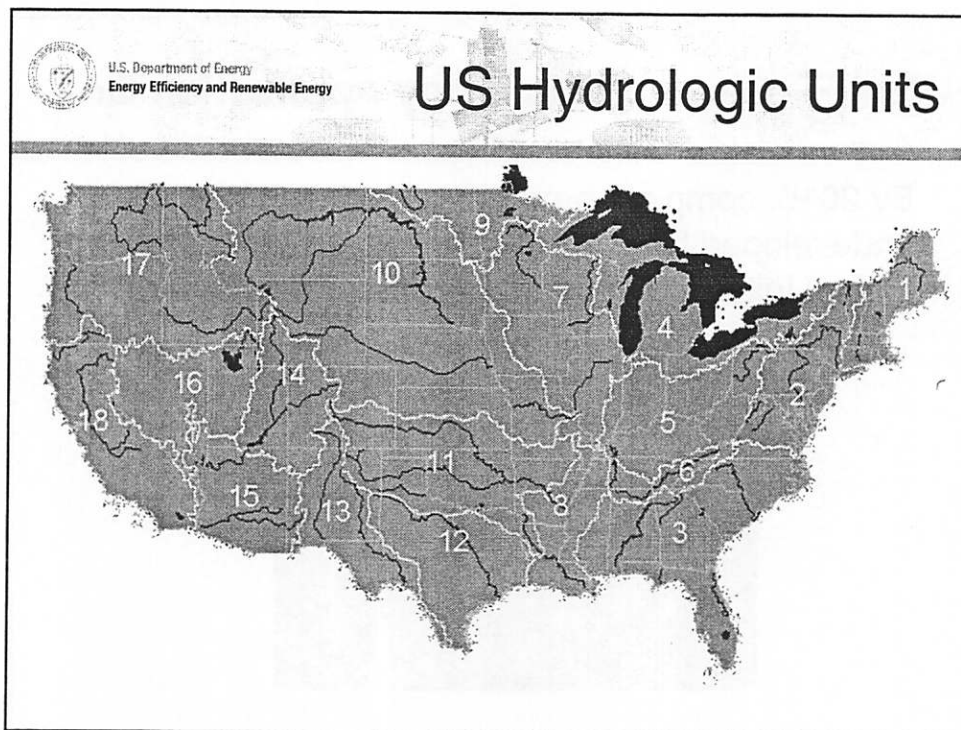
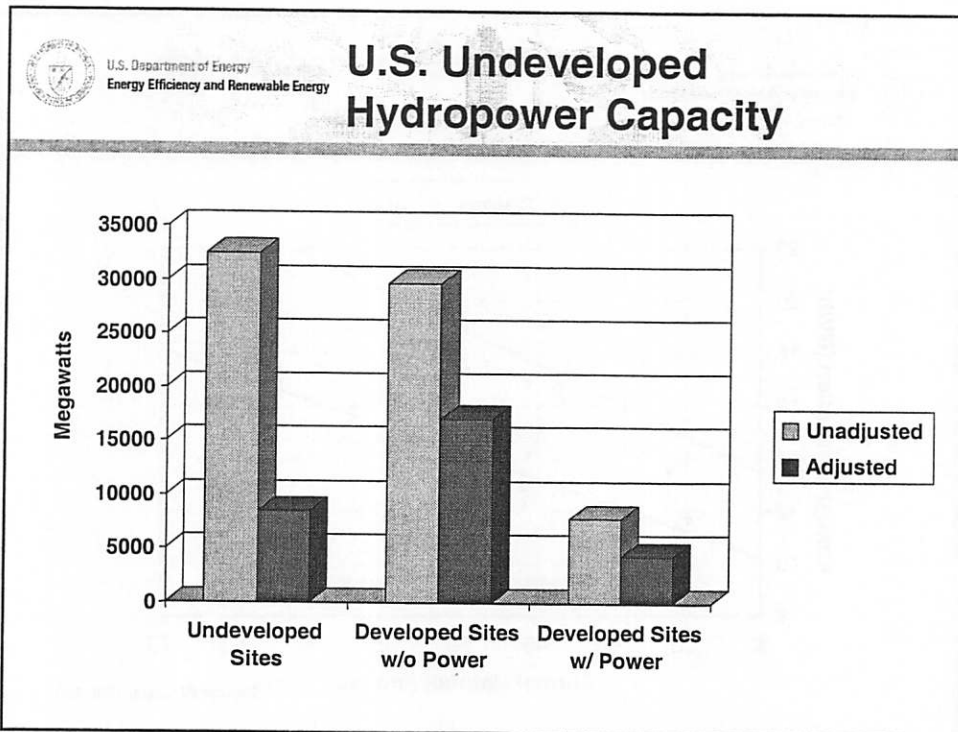


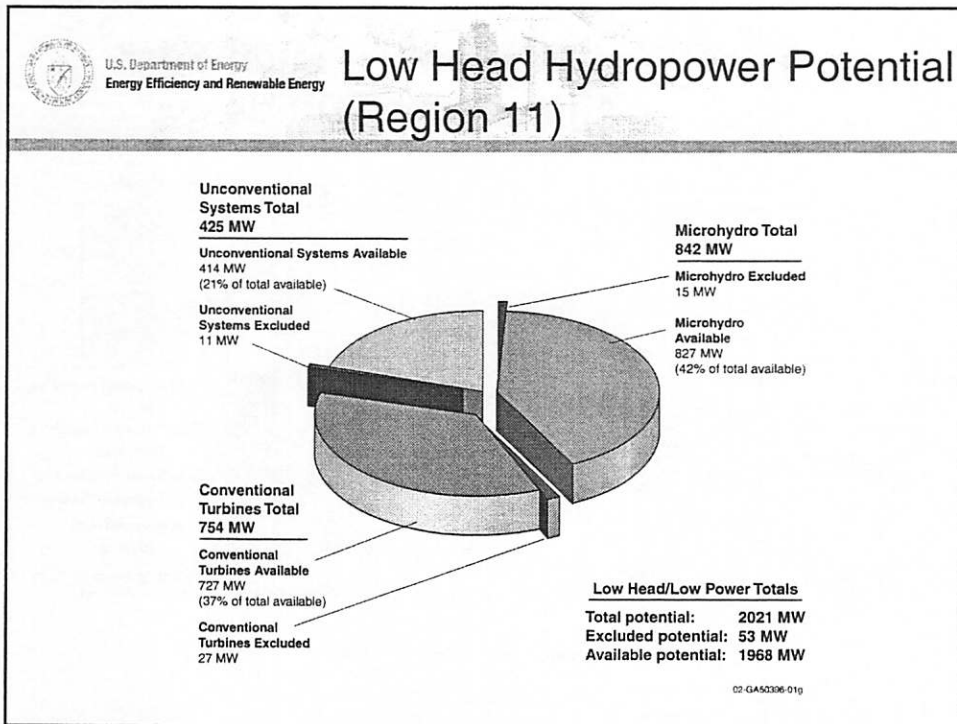


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Technology Application Goal

By 2010, complete program activities to enable undeveloped hydropower capacity to be harnessed in the United States without constructing new dams.

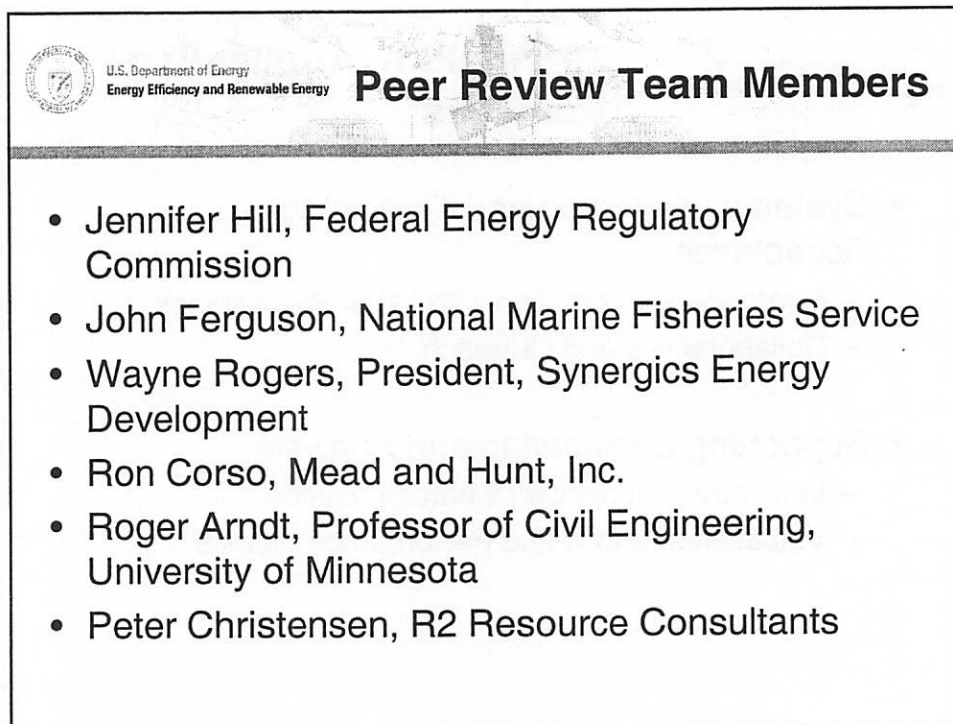
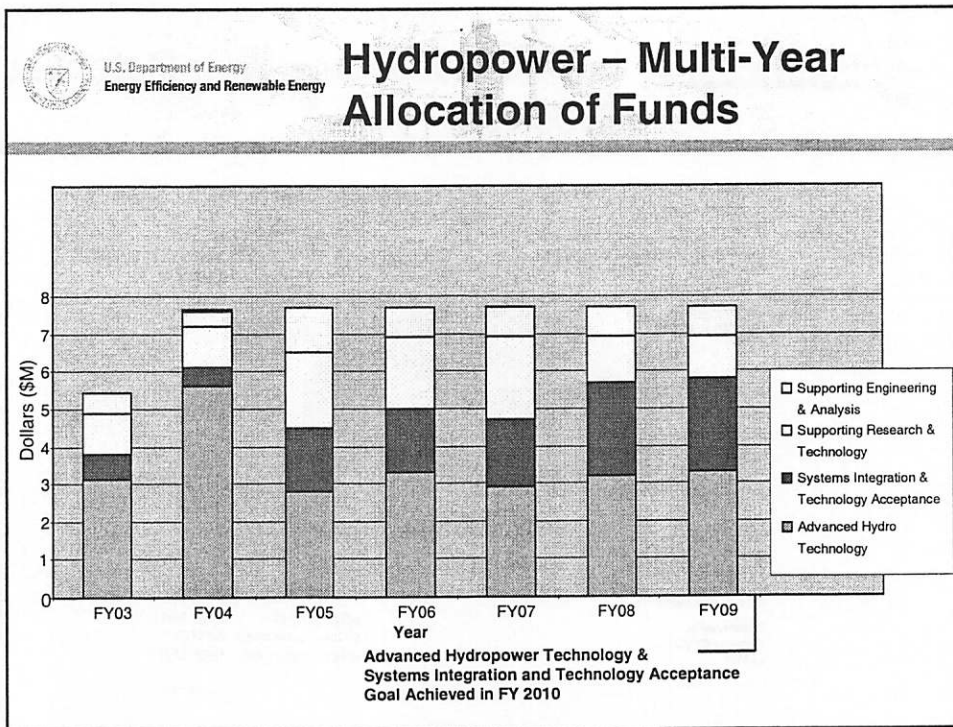


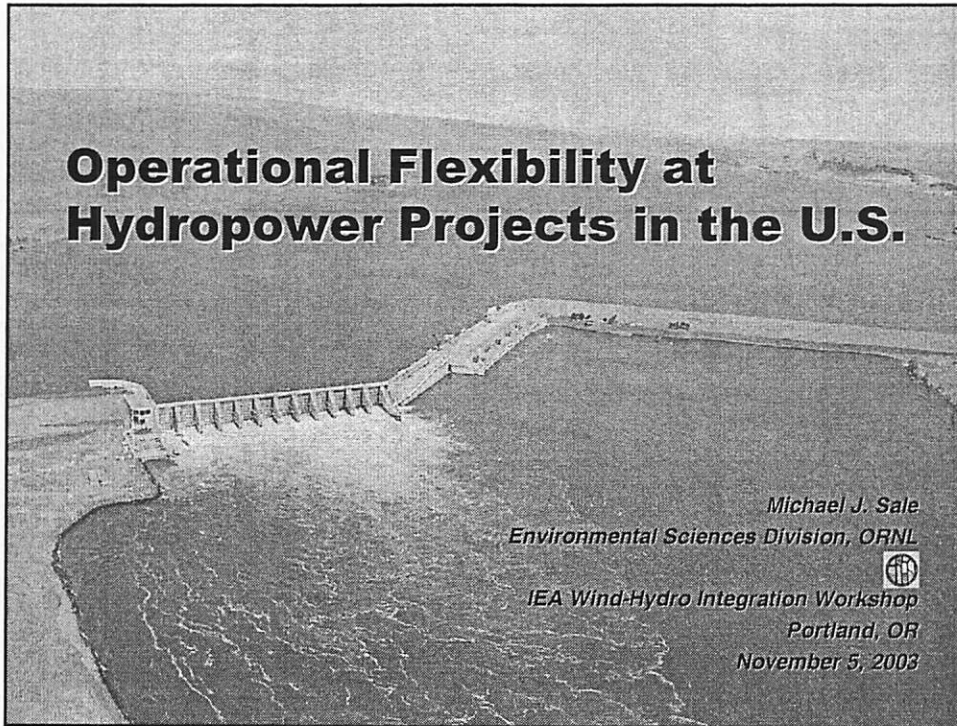


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Technology Application Activities

- Systems Integration and Technology Acceptance
 - Hydropower Integration with Other Renewables
 - Collaboratives and Outreach
- Supporting Engineering and Analysis
 - Innovative Technology Characterization
 - Valuation Methods and Performance Metrics





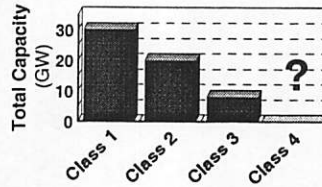
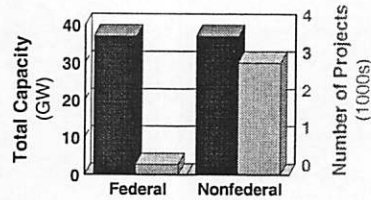
Wind-Hydro Integration depends on operational flexibility

- **Integration goal: maximize system dependability (wind+hydro)**
- **Approach: shift hydro generation to periods of low wind availability**
- **Potential benefits**
 - new product for hydro (“firming/shaping”)
 - marketability of wind (part of integrated system)
 - wind energy complements hydro in low water years (?)
 - water savings (?)
 - improved renewables package

Hydropower Resource Classes

To get a complete picture of the full range of undeveloped hydropower resources, it is useful to define a new classification system:

1. *New dams or diversions with advanced design*
2. *Retrofits of new power plants at existing dams w/o power*
3. *Incremental power upgrades at existing power plants*
4. *Low-head/low-power projects without dams ("kinetic energy")*



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Project purposes and demands are the drivers of flexibility

- **multipurpose objectives:**
 - navigation
 - flood control
 - water supply
 - environmental quality
- **power sales agreements**
- **water rights**
- **water deliveries (irrigation, pollution, navigation)**
- **seasonal flood control rules**

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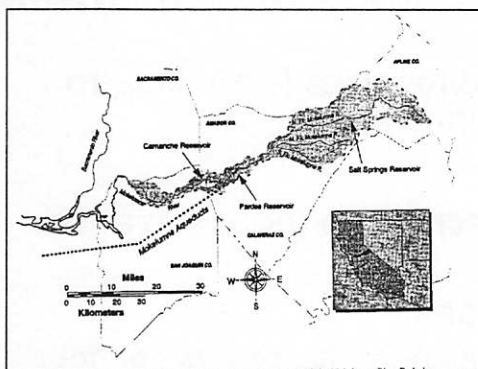
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Hydropower operation is a matter of balance:

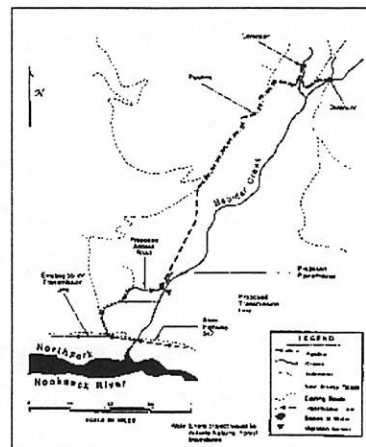
$$Q_{out} = Q_{in} - \Delta S - W - E$$

- project configuration (storage, ROR, peaking/pulsing)
- reservoir volume assignments (e.g., active, flood, environmental allocation)
- rule curves and seasonal adjustments
- relative storage (e.g., active pool/QAA)
- other project characteristics:
 - min/max hydraulic capacity
 - min/max generation
 - high/low pool elevation limitations

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Storage projects in multireservoir river basin



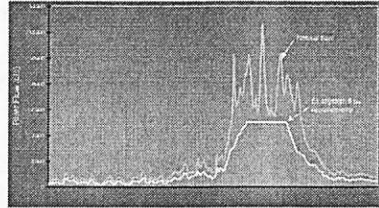
Diversion, ROR project

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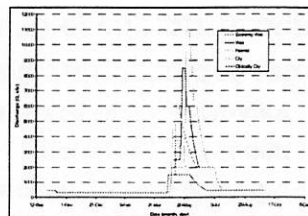


Hydrology is the basis for operation

- annual hydrograph type
- river basin type and configuration
- hydrologic variability / water year type
- upstream reservoirs and river basin type
- changing values for environmental protection



Annual hydrograph example



Seasonal minimum flows

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Environmental requirements are having more influence on operation

- instream flow requirements (from Q_{\min} to natural/normative flows)
- recreational flows
- reservoir-based recreation (pool elevation constraints)
- Stakeholder relations:
 - reservoir/project operator (fed versus non-fed)
 - regulatory agencies (FERC, others) and status
 - operating agreements

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Wind-Hydro matches depends on project characteristics

Good combinations:

- large storage reservoirs
- multiple dams w/ reregulation capability
- flexible power/water contracts
- Others?

Bad combinations:

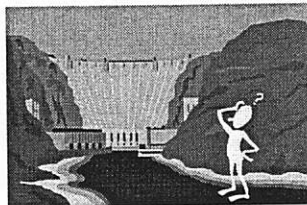
- overallocated projects
- ROR projects with little/no storage
- projects subject to ESA or other institutional problems
- Others ?

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Conclusion: situation complex but not hopeless

- bottom line: where are the values
 - “... water flows to money”
- other storage options may benefit both
- technology solutions:
 - reregulating weirs
 - better science for instream flow requirements
- wind will have to join the crowd of demands on hydro



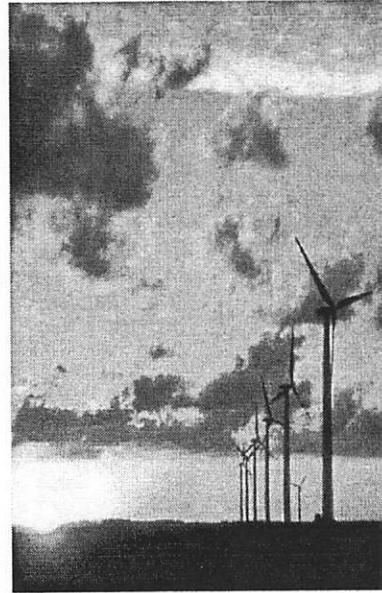
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IEAWind-Hydro Integration Expert Meeting

Portland, Oregon
November 5-6, 2003

Brian Parsons
**National Wind
Technology Center**
brian_parsons@nrel.gov
303 384-6958



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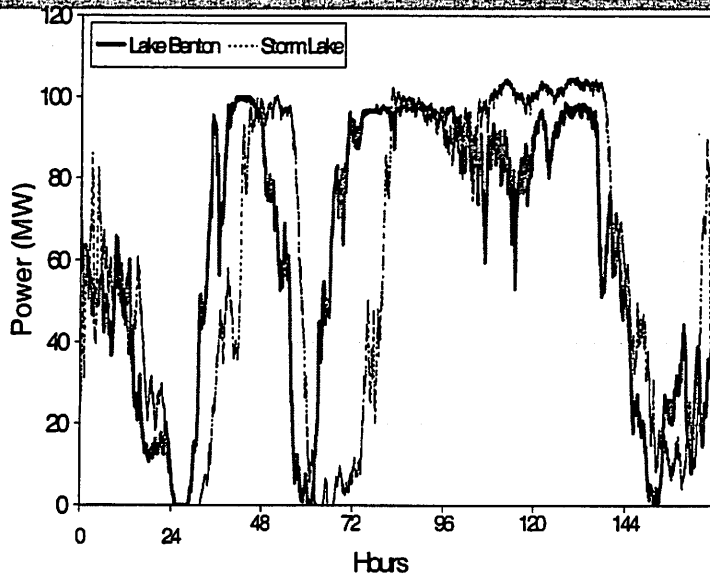
Meeting Objectives

- identify technical, institutional, economic, and political issues associated with integrating wind and hydro electric generation
- inventory and discuss lessons-learned from prior work around the world
- discuss ongoing and potential future work in the area
- consider establishing a formal technical IEA Wind-Hydro integration activity



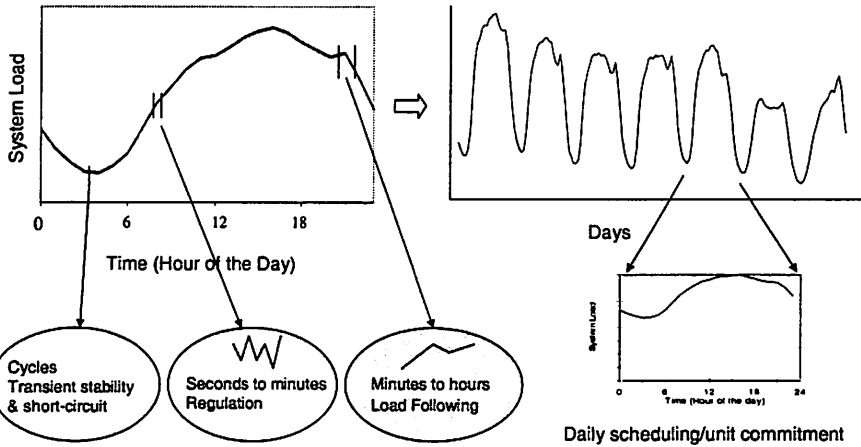
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Wind Farm Power Fluctuations



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Time-frames: Power System Operations






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Costs of Wind Variability

Study (Penetration)	Time-Scale	Cost (\$/MWh)
Hirst PJM (0.06-0.12%)	Reg, Imb	0.05-0.30
Electrotek Xcel (3.5%)	Reg, LF, Res, UC	2.00
PacifiCorp (20%)	Imb, Res	5.50
Hirst BPA (6%)	Reg, LF, Imb, DA	1.37-2.17

Reg=regulation, IMB=imbalance, LF=load following,
Res=reserves, UC=unit commitment, DA=day ahead market
www.osti.gov/servlets/purl/15004469-1r8Tgt/native



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Wind Power's Natural Characteristics

- **Variable:** Plant output varies with variations in the wind
- **Remote:** Wind resources often distant from major markets
- **New:** Operators more comfortable with established power technologies, old policy frameworks do not apply



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Hydropower's Natural Characteristics

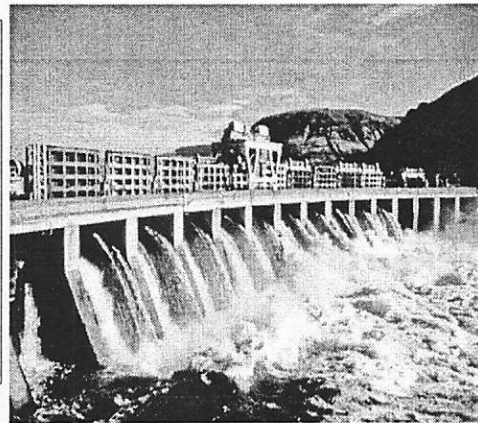
- **Variable:** Seasonal and annual flow fluctuations
- **Constrained:** Multiple demands dictate flows, increasing environmental pressure
- **Quick Response:** Rapid regulating and high ramp rate capability
- **Built-in Storage:** System-specific ability to time-shift output




U.S. Department of Energy
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Potential Hydro Synergies

- Hydro as short-term wind buffer, wind allow longer-term water time-shifting
- More flexibility in operations of both power sources
- Better utilization of transmission
- Green power markets
- Enhancement of public benefits




Key issue: *multiple constraints on hydro, how much flexibility and will wind help or hinder?*



U.S. Department of Energy
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Factors to be considered

- ***Technical:*** controllability and response of generators, transmission links, demand profiles, inflow variability
- ***Institutional:*** agencies and responsibilities, multiple constraints (fish other wildlife, irrigation, navigation, flood control, recreation, energy/power)
- ***Economic:*** value tradeoffs and market prices
- ***Political:*** use of allocations and competing power interests



U.S. Department of Energy
Energy Efficiency and Renewable Energy

U.S. DOE Wind and Hydro Program Activities

- *WAPA Cooperative Analysis (goal: highlight opportunity and motivate use of the system)*
 - *Arizona Power Authority Colorado River Scoping*
 - *Missouri River System Potential: tie to Wind on the Wires effort*
- *Tom Acker, Northern Arizona University
Sabbatical 9/1/03-4/30/04*



U.S. Department of Energy
Energy Efficiency and Renewable Energy

U.S. DOE Wind and Hydro Program Activities (cont.)

BPA Cooperative Analysis

- much internal activity already underway as follow up to Eric Hirst report and UWIG/Electrotek work*
- 1 week delay, equivalent energy firming product offering expected soon*
- we need to focus on added value supporting analysis*
 - Hedge value of wind on a dry year*
 - Ability to shift water to times valuable to fish*
 - Wind forecasting tie to hydro operations*

Status of NREL Wind/Hydro Work

Tom Acker

Associate Professor, Mechanical Engineering, NAU
Sabbatical Researcher, NREL



Approach



- ◆ Problem characterization and definition
 - Technical, organizations, modeling
- ◆ Study of technical feasibility
- ◆ Economic studies and benefits assessment
- ◆ Case studies
- ◆ Education and outreach



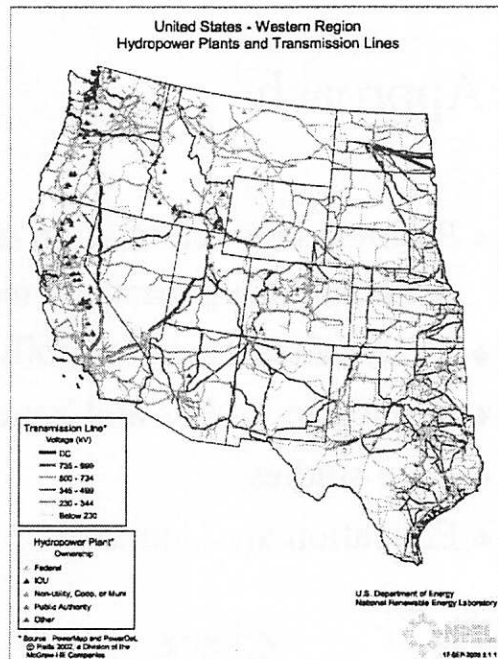
Problem Characterization



- ◆ Literature review / lessons learned
- ◆ Characterize technical challenges of integrating hydropower and wind systems
 - river operations
 - generation system control and operation issues
 - transmission
- ◆ Devise plan for study of these challenges.
- ◆ Collaborate with appropriate institutions

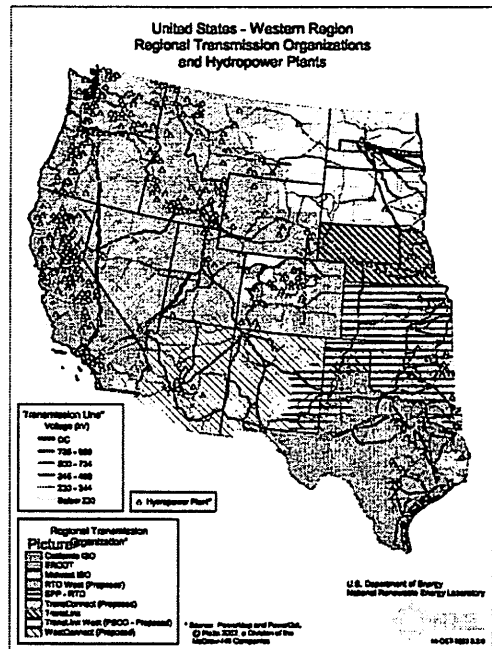


Hydropower in the American West



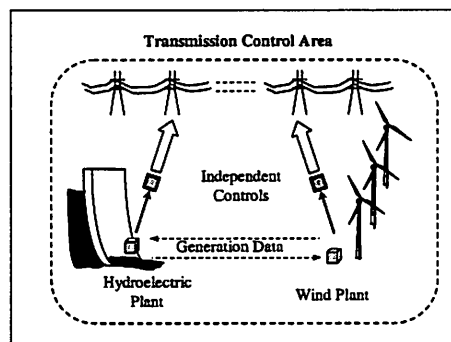
Transmission Regulation

- ◆ Regional transmission organizations
- ◆ Transmission control areas



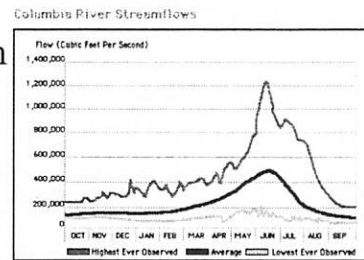
Technical Feasibility

- ◆ Wind/hydro resource availability
- ◆ Hydro system operation and modeling
- ◆ Transmission availability and access
- ◆ Economic and optimization studies



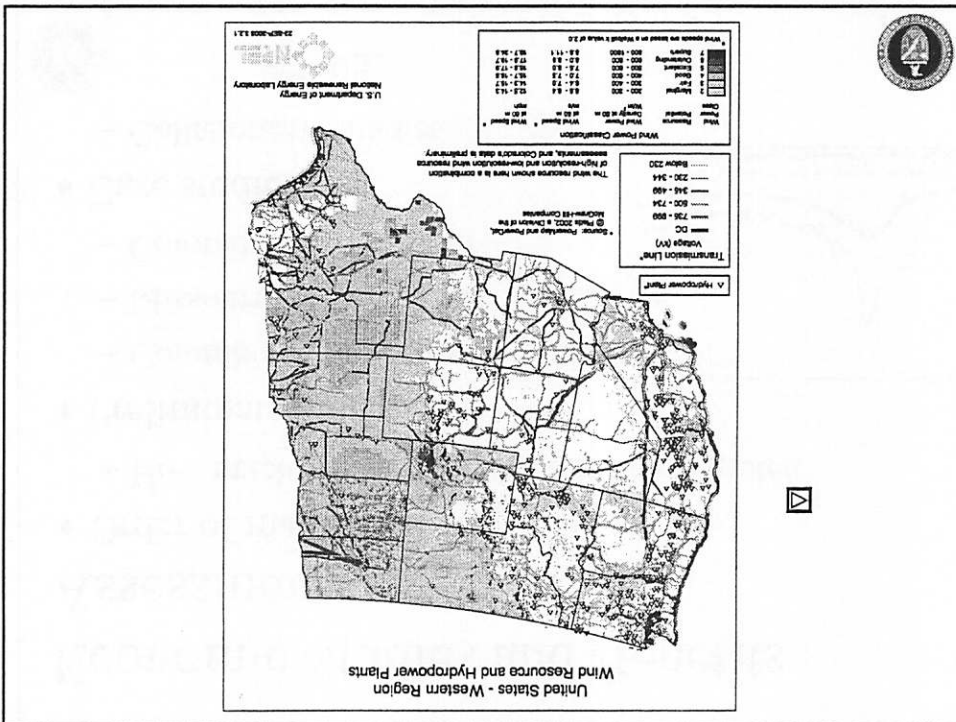
Economic Studies and Benefits Assessment

- ◆ Order of magnitude
 - How much wind and hydro can be integrated
- ◆ Preliminary studies
 - Columbia & Snake river system
 - Missouri River system
 - Colorado River system
- ◆ Case studies
 - Collaborative studies



Questions, Comments, Suggestions?





Challenges & Opportunities for Hydropower & Wind Integration

Deborah M. Linke
Manager, Power Resources Office
US Bureau of Reclamation
Portland-November 2003

Overview of Reclamation Power Program

- 2nd largest hydroelectric power producer in US
- Annual revenues of nearly \$1 billion
- 58 hydroelectric power plants
 - 194 generating units
 - 14.7 million kilowatts of installed capacity
 - 42 billion kilowatt hours of energy
 - Energy equivalent: 13 million cubic meters of crude oil (80 million barrels)

Reclamation's Service Area



Power Program Context

- Hydropower plants built as part of water development projects
- Water deliveries come first
- Hydropower generation a result of water deliveries
- Reclamation generates power for project purposes
- Surplus power available to Power Marketing Administrations (Bonneville & Western) for sale at cost based rates

Legal and Contractual Context

- Water marketed via long-term contracts for irrigation and municipal purposes
- Water deliveries subject to project specific authorizing law and environmental requirements
- Power marketed through public process via long-term contracts
- Power marketed is based on long-term average hydrology

Marketing Context

- Power is allocated through a lengthy public process for each marketing system
- Many customers have typically received power since project inception
- In most cases power has been sold as a bundled product
- Customers have high level of interest in ensuring long-term availability of hydro power
- Concern about on-peak versus off-peak price differential

Operational Context

- Each power system is different
- One size does not fit all
- Capability to integrate wind power differs among regions
- Since capability differs equity in allocating integration ability is important
- Capability is not unlimited
- Concern about on-peak versus off-peak price differential

Customer Context

- Concerned about impacts on rates
- Concerned about ability of system to absorb wind/hydro integration
- Concerned about impact to system reliability
- Concerned about the long-term product reliability and availability

Reliability Context

- Reserve calculations
- Regulation requirements
- Load following impacts
- Technical interconnection requirements

Opportunities

- Renewable energy partnership between wind and hydro beneficial
- Opportunity for large hydro to become environmentally preferable
- Opportunity for customers to have firmed wind power
- Opportunity for green tag certification

Contact Information

- Deborah M. Linke
Manager, Power Resources Office
US Bureau of Reclamation
303-445-2923
dlinke@do.usbr.gov

Integration of Wind and Hydro Power Systems

A discussion on the minimization of cost (or optimization of value?) of wind integration for grid operators

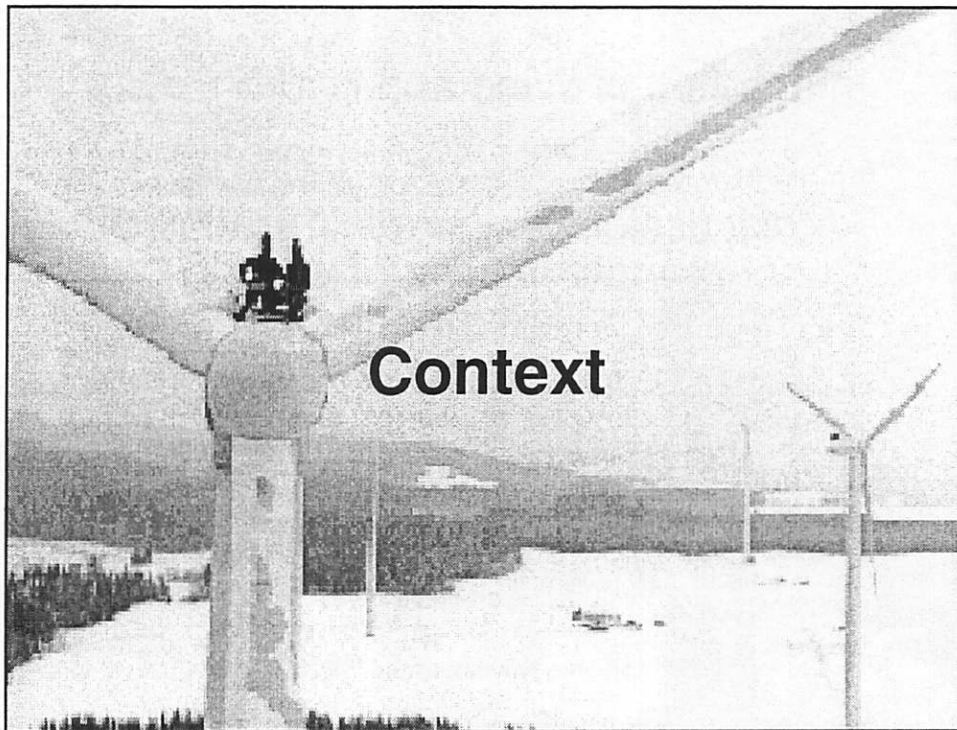
A. Forcione, B. Saulnier, S. Krau
 Research Scientists, Hydro-Québec Research Institute (IREQ), Canada
 G. Lafrance
 Professor, INRS, University Of Québec, Canada

IEA R&D Wind
 Topical Expert Meeting #41
 Portland, November 5-6 2003




Content of the presentation

- Context
 - Canadian electricity context
 - Hydro-Québec's electricity, "hydro" and market context
- Answers
 - Mid-term management
 - Interconnections and spot market effects
 - Comparing to other generation sources
- Ongoing research
 - Short-term management
 - Electrical modelling
 - Wind "inflow" modelling



Hydro Québec



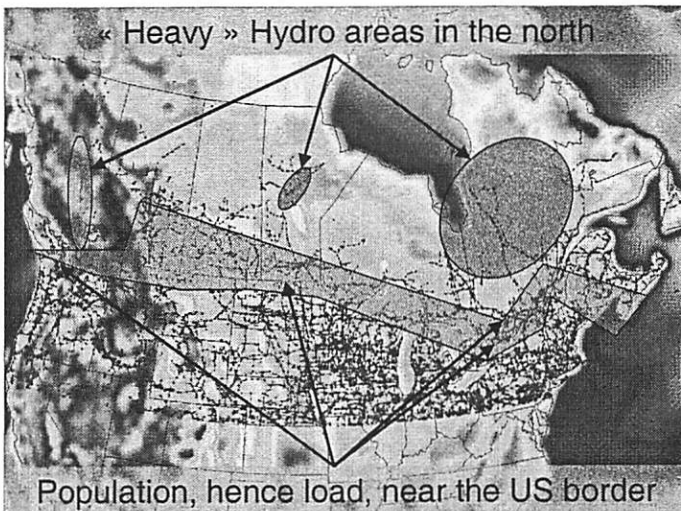
Canadian Electricity Context

Electricity Generation Mix

- 62% Hydro
- 26% Fossils
- 12% Nuclear
- Small wind base with 236MW installed (Sept. 2003)
- 550 TWh in 1999

Hydro Located in Remote Areas

- Extensive electrical network
- Relative distance

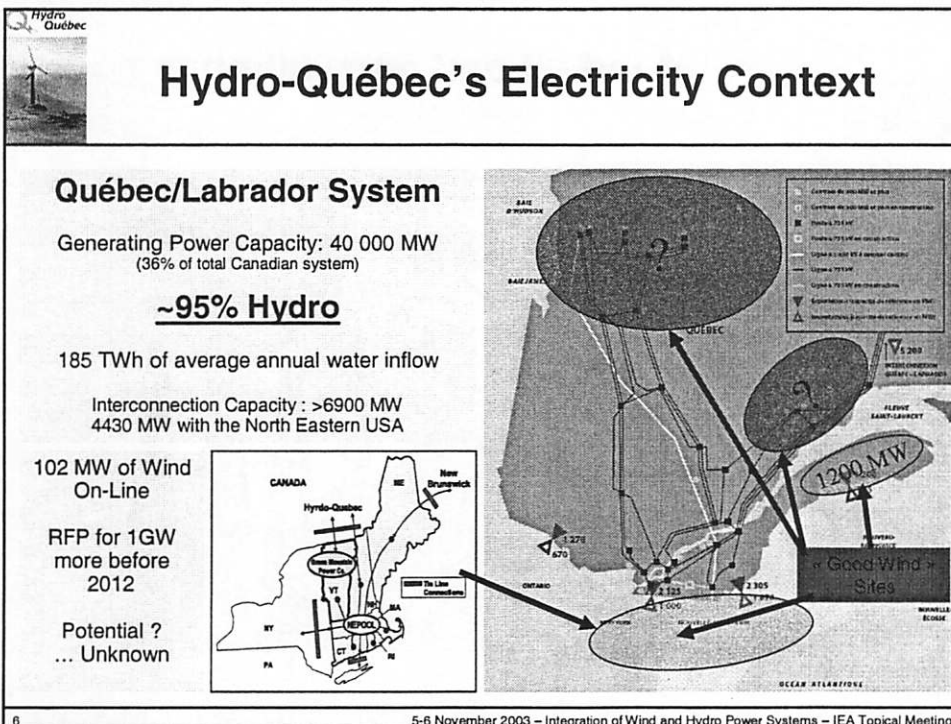
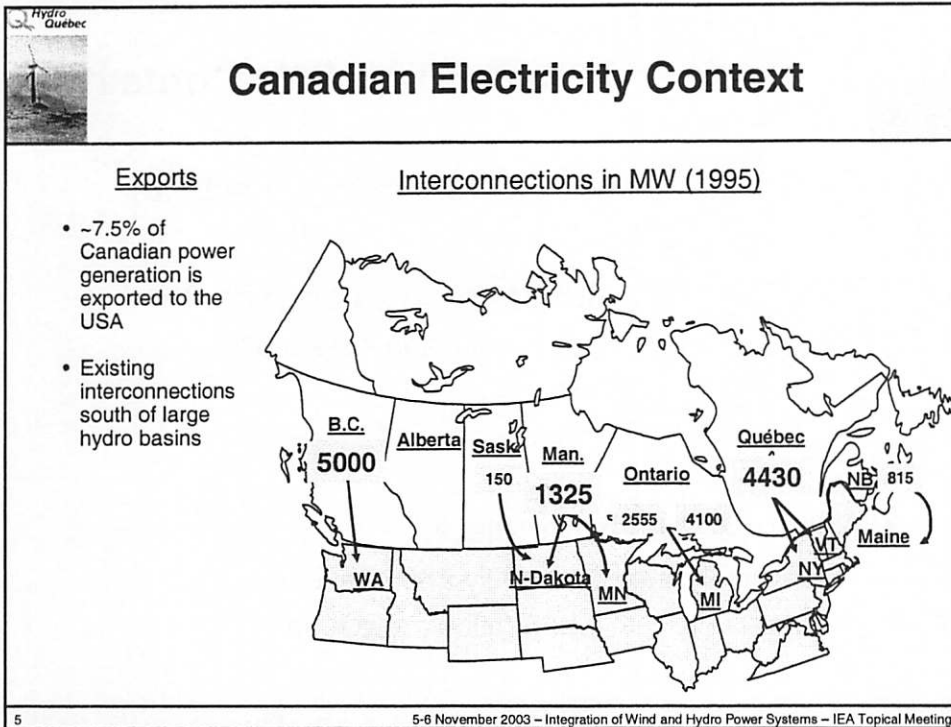



« Heavy » Hydro areas in the north

Population, hence load, near the US border

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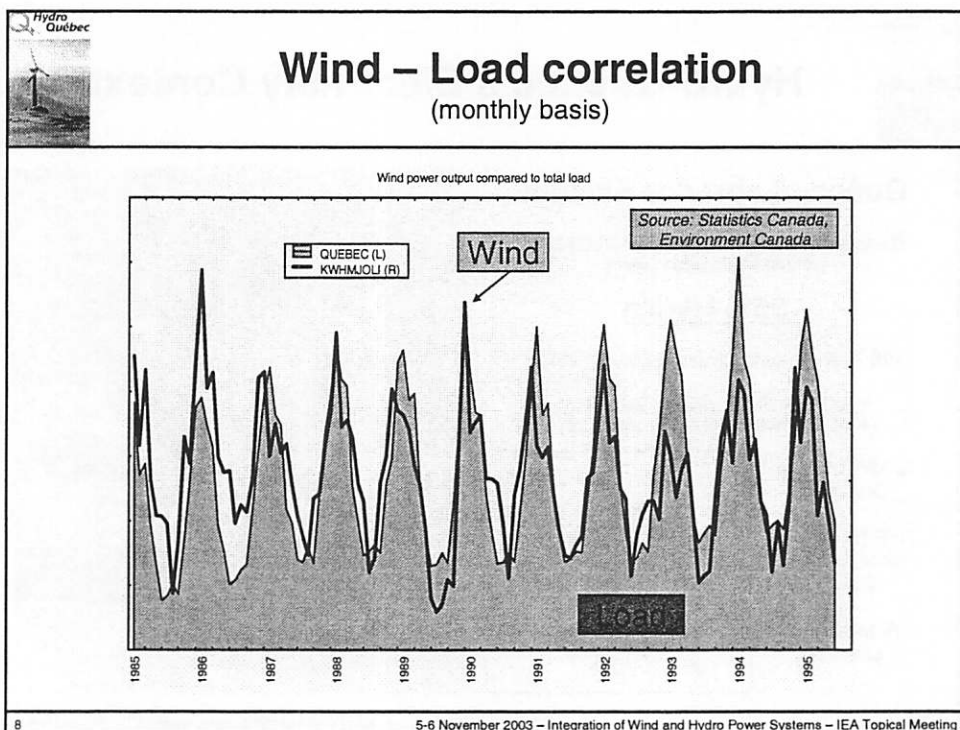


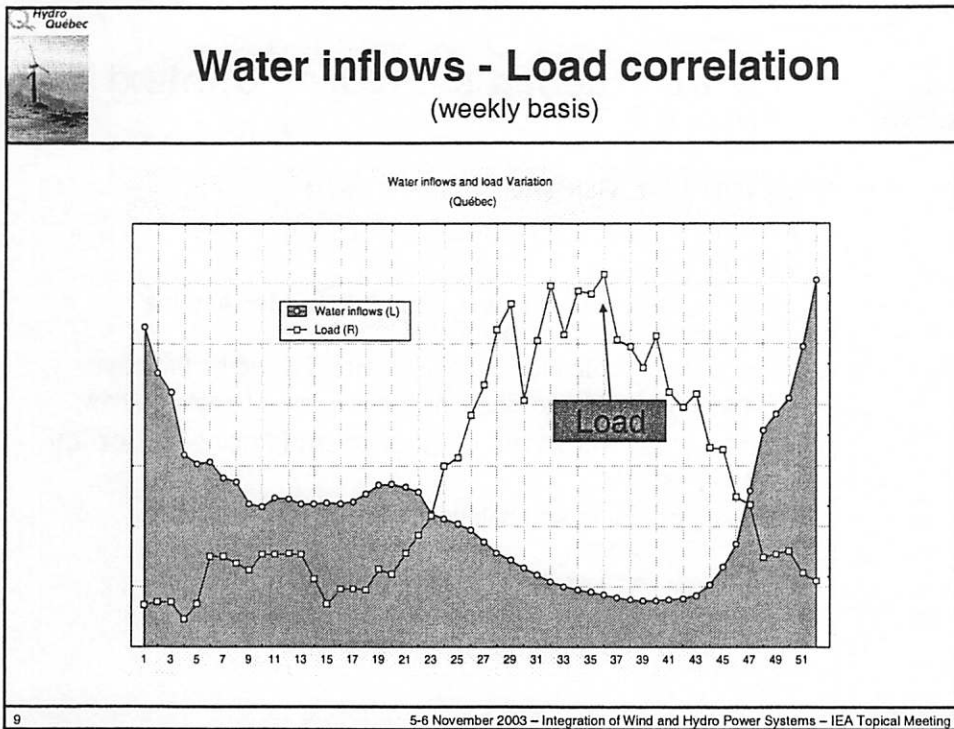


Hydro-Québec's Electricity Context

- Electricity is cheap: 3.4 ¢_{US}/kWh (wholesale)
- Massive resistive heating in a cold climate
 - Load is highly cycled daily and seasonally
 - High diurnal peaks
 - High winter peaks
- Electrical load is correlated
 - positively with wind, daily and seasonally
 - negatively with water inflows seasonally

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Hydro Québec

Hydro-Québec's "Hydro" Context

- What does "Large Hydro" mean for Hydro-Québec ?
 - Coordination of a system of multi-annual, mid-term and short-term reservoirs, interlinked into basin large management systems
 - Example of the "La Grande" River basin
 - 16 GW of installed power in 8 multi-turbine plants
 - 7 reservoirs totaling 12000 km² (4650 mi²)
 - An area as large as Connecticut... or 40% of Belgium
 - High voltage lines stretched over distances equal to New-York-Chicago
 - Impacts on ecosystems comparable in size to many European countries
 - Years to fill

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Hydro-Québec's "Hydro" Context

- Reservoir management
 - Within one basin, "chained" hydro plants are constrained by
 - Each other, depending on their configurations and the capacity of their own reservoirs
 - Inflow, the fluctuating volume of water drained by the basin
 - Other limiting factors like minimum/maximum water outflow
 - System wide, reservoir management is constrained by reliability issues
 - Capacity reserve and balancing of load level and other generation plants
 - Electrical limits on the transmission system
 - Other limiting factors like contractual clauses, interruptible/non-interruptible exports

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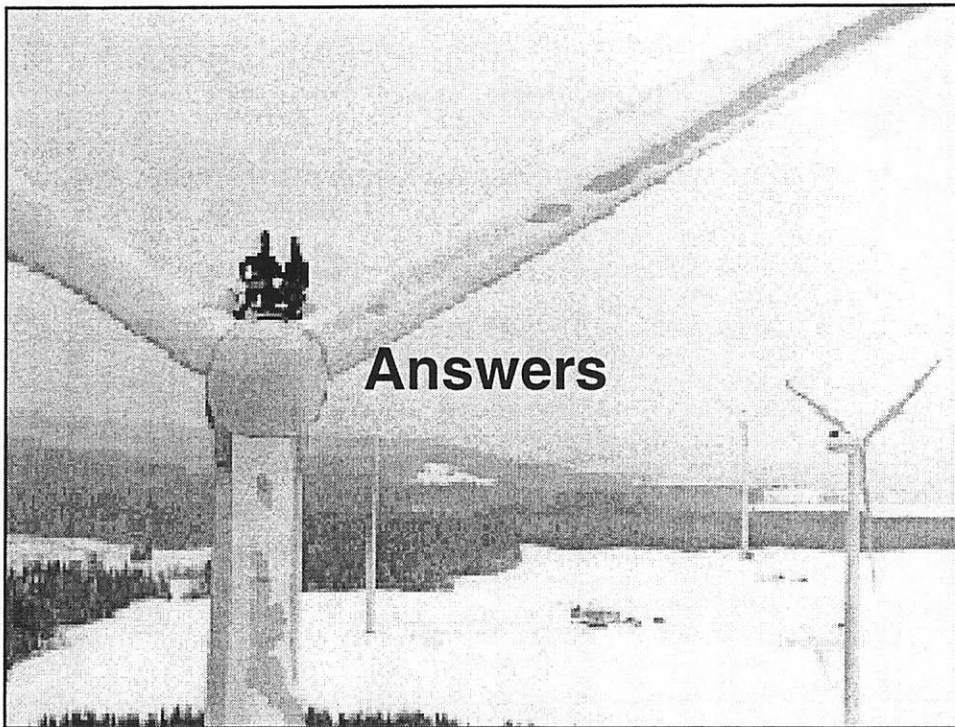


Hydro-Québec's Market Context

- Today's market context
 - Maximize revenues
 - Import/Export electricity with neighbouring networks
 - Seasonally, the NEPOOL price is negatively correlated to Québec's demand
 - "Load managing" the increasing demand
 - Guarantying the future
 - Maintain a sufficient annual water reserve
 - Invest in new generation capacity


**Apart from its base COE,
Is integrated wind power competitiveness improved
 in a large hydro system?**

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Seeking Different Levels of Answers Mid-term management modelling


- One reservoir
 - Not closely tied to operating practices
- One basin
 - Regional generator's constraints included
 - Demand and grid limiting factors still excluded
- ...
- System wide wind/hydro integration
 - Interconnections and spot market effects
 - Comparing to other generation sources



System wide wind/hydro integration Using the SAGE Model

- Deterministic mid-term generation planning model called SAGE (presently used at *Hydro-Québec Production*):
 - Parameters
 - Time step : day/week - Horizon time : 1 year
 - Demand classes : one to three per day
 - Wind generation is predetermined
 - Area of interest is divided in regions based on the configuration of main transmission lines
 - Each region has a load to satisfy and production plants
 - Interconnections with neighbors are modeled
 - The generation of a hydro-plant is modeled in taking account the water head
 - Constraints:
 - Electric constraints (capacity on transmission lines).
 - Hydraulic constrained (reservoir volume, river section flow, water flow conservation, etc...)
 - Objective : Satisfy load at minimum costs

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Interconnections and spot market effects Vermont Study – Case I

- Base case: Vermont with the NEPOOL
 - No possibility, inside Vermont, to manage wind with large hydro plants
 - Typical thermal system
 - Limited, highly constrained, short term energy storage
 - Vermont depends essentially on imports
 - No correlation between Vermont wind and spot price
 - No clear correlation between Vermont wind and load
 - Thermal heating during the winter

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Interconnections and spot market effects Vermont Study – Case I

- Results

- Technically, high penetration of wind is possible in Vermont today, but...
- Economically, wind value depends strongly on NEPOOL spot price
 - Required price support of 1.32 cents/kWh today
 - Depending on assumptions for pool price and wind COE changes by 2010, range of needed support is either negative or positive

Change in COE Needed For Wind To Break Even In 2010 (cents/kWh, year 2000 dollars)			
Average Annual NEPOOL Wholesale Price - cents/kWh (% change from 2000 value)	Percent Change From 2000 Average Wind COE of 5.4 cents/kWh		
	-32%	-24%	0
3.9 (-10%)	0	0.4	1.7
4.3 (0.0%)	-0.4	0	1.3
5.7 (32%)	-1.7	-1.3	0

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Interconnections and spot market effects Vermont Study – Case II

- Base case + interconnections with Hydro-Québec and coordinated management
 - Best case scenario
 - Perfect correlation of HQ Price and Quebec's load was assumed
 - Selling stored energy when negatively correlated spot price/Québec's load were favorable
 - Results
 - Hydro-Québec's reservoirs were able to better optimize Vermont's wind energy value, thereby adding value above NEPOOL spot prices
 - Value of wind was 22% higher than if it were sold only at NEPOOL spot prices
 - Actual savings would be below this figure

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Comparing to other generation sources Hydro-Québec study

- Integrating increasing amounts of energy from “other” generation sources with the hydro system
 - A large wind energy volume (more than 10 TWh) can be managed optimally by the hydraulic assets
 - Up to certain proportions (~10-20%), the annual generation profile ($P=f(t)$) of an energy source does not bring any particular value or cost when managed through large hydro storage
 - In the worst case, wind competes with other sources on the base of its COE
 - In a “power deficit” situation, wind integration value depends on:
 - Interconnections with neighboring systems
 - Correlation between wind and market spot price
 - Verification including stochastic nature of wind to be done






Seeking Different Levels of Answers Short-term management modelling

Again

- System wide management is constrained by short-term efficiency and reliability issues
 - Part of the answer comes through electrical modeling of short term effects
 - Electrical limits on the transmission system
 - Part of the answer comes through short term modeling of wind power and energy “inflow” management


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Short Term Electrical Modeling

- SimPower System (Matlab), PSS/E, EMTP, HyperSim
 - Models of turbines
 - Small installations
 - Large wind plants
 - Regional and system effects
 - Frequency
 - Voltage
 - Harmonics
 - Etc.


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Short Term Wind “Inflow” Modelling

- Development of models
 - Capacity reserve and hydraulic balancing of wind output
 - Unit scheduling and commitment
 - ...
- Optimization possibilities
- Wind forecasting
- ...

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A Continuum of Systems

- System specificity
 - Rarely possible to directly extend a conclusion from one location to another
- But still a continuum of configurations
 - From a large scale wind-hydro system at one end to a small remote high penetration/no storage wind-diesel system at the other:

Conceptually similar, but improving wind value in the large system requires fine tuning to achieve economic leverage

What is the residual added-value of wind in a large scale hydro system ?

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References

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- [2] Lafrance G, S. Krau, B. Saulnier and. al. Assessment of the Impact of Wind Power Penetration on the Vermont Electricity Grid, Technical Reference 1 of 3; U.S. DOE project DE-PS01-00EE10722, with Green Mountain Power Corporation, December 2002; 1-53.
- [3] S. Krau, G. Lafrance, L. Lafond, Wind power integration: A comparison with a traditional hydro option, Global Windpower Ewea Conference, 2-5 April 2002, Paris.
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- [5] D. Ancona, G. Lafrance, S. Krau, P. Bezrukikh, Operational Constraints and Economic Benefits of Wind-Hydro Hybrid Systems, Analysis of Systems in the U.S./Canada and Russia, EWEA, Madrid, June 16-19, 2003.
- [6] J.Cohen, G. Lafrance, and S. Krau, Analysis of Wind Hydro Integration Value in Vermont, WINDPOWER 2003, Austin, Texas, May 21, 2003



BPA Storage and Shaping Service *Recent Developments and Challenges*

Elliot Mainzer
Manager, Pricing Desk
Bonneville Power Administration
IEA Topical Experts Meeting
November 5-6, 2003



Overview

- Update on recent activities
- Within-hour impacts of wind integration
- Federal Hydro System advantages
- Valuing Storage and Shaping Service
- Transmission challenges



Background

- Over the past two years, we have been undergoing an effort to assess the costs of integrating wind into the Federal Columbia River Hydroelectric System.
- We also developed a Storage and Shaping Service for new wind projects.
- Our analytical and pricing efforts are now complete.
- Our analysis of day-ahead and within-hour impacts was largely consistent with the findings of the Eric Hirst study.
- We established a price of \$6.00/MWh for Storage and Shaping Service, not inclusive of transmission.



Within Hour Impacts

- The key finding of the Hirst study was that wind forecast errors are not correlated with load forecast errors and therefore the incremental contribution to variance from introducing wind into the BPA control area is quite small.
- Analysis of the data, extended over a longer period of time, and close collaboration with the Transmission Business Line, verified this finding.
- Applying the same methodology that the TBL uses to size its control area regulation requirement, we quantified the incremental average regulation requirement from introducing up to 1000 MW of wind into the system. This value was less than 100 MW.

The Value of Surplus Capacity

- Hirst argued that the BPA system had 6,000 MW of surplus capacity. This was judged to be overly optimistic. However, under most conditions, BPA *does* have a healthy surplus of short-term capacity and this surplus is a valuable asset for BPA. It gives us an advantage in dealing with the "tail events" that result from integrating wind.
- When wind generation differs substantially from its schedule in a way that dramatically exacerbates regulation requirements, BPA can lean on its hydro units to remedy the imbalance. Other systems will likely have less of this type of flexibility and will have to carry larger amounts of reserves.
- Moreover, the ~100 MW of regulating capacity does not eat substantially into BPA's overall surplus capacity inventory and therefore its opportunity costs are limited.

S&S Service Mechanics

- Wind project X, interconnected to the BPA control area, schedules and delivers energy into the BPA system on an hourly basis.
- At the end of each day, PBL averages the scheduled (and delivered) Peak and Off-Peak generation from the project. This amount of power is then redelivered a week later in flat Peak and Off-Peak blocks.
- The one week delay allows the end-use customer to plan its system for redelivery volumes and takes the hour-to-hour uncertainty out of the wind generation.
- Features are very similar to a service provided to BPA by PacifiCorp for Wyoming projects and comparable to a service that BPA provides to PGE to integrate the Vancycle Wind Project.

Pricing Storage and Shaping

- Team analyzed an array of important issues that affect the costs of providing this service:
 - Minimum generation constraints.
 - Seasonal capacity headroom.
 - Impacts on spill.
 - Expected price differences between heavy load and light load hours.
 - Impacts on Slice customers.
 - These factors all influence the Power Business Line's opportunity cost of offering the service.
 - Used standard BPA hydro and price models to value the service.

Pricing Storage and Shaping

- The essential intuition of pricing Storage and Shaping Service is as follows:
 - At any one time, you have two things happening – wind generation coming into the system and an outgoing scheduled redelivery of power from the previous week. To the extent that the amounts of energy entering and leaving the system are identical, BPA does not have to lean on its system capacity to make the redelivery. To the extent the values differ, BPA must deploy system capacity that can otherwise be used for secondary marketing.
 - We spent considerable time looking at the week-to-week correlation of wind generation and determining how much capacity, on average, we would have to withhold to ensure we could satisfy our net redelivery obligation.

Pricing Storage and Shaping

- We defined an "expected" case based on the statistics and then chose an appropriate point on the distribution of monthly net redelivery volumes that gave us a statistical edge on the service.
- We were more conservative during times of the year when the BPA system tends to be relatively constrained.
- The opportunity costs of withheld capacity were quantified by assessing changes in the volume and diurnal shape of marketable secondary energy and then valuing these MWhs against a forward price curve.
- We also assessed the impacts on our ability to load factor the system at night, since variable amounts of wind power will cause us, under certain circumstances, to run the system above minimum generation levels to assure we have enough ramp-down capability to absorb the wind.

Pricing Storage and Shaping

- Our \$6.00/MWh price includes the intra-hour regulation and load-following costs, the opportunity costs of withheld capacity, and an adder for risk. If other utilities can beat our price, we encourage them to step up and offer the service.
- We will be working actively with our Operations and Real Time groups, and the TBL, to closely monitor these costs as we gain experience marketing the service. Our intention is to offer approx 350-400 MW of the service over the balance of the current rate period (through 2006.)
- We have assumed no changes to the rules for generation imbalance with respect to Storage and Shaping Service. Generators will still be liable for deviations from their schedules.
- The \$6.00/MWh will be escalated annually at the GDP Implicit Price Deflator, same as the PTC.

Transmission Challenges

- Because of the way that the regional grid is configured, Storage and Shaping Service requires two wheels – one *into* the BPA system and one *out* of the BPA system.
- Starting with two Point-to-Point wheels, the transmission costs can increase the price of S&S Service to as high as \$18.00/MWh.
- Developing strategies to manage the transmission costs is a critical challenge facing BPA as we attempt to sell this service to entities outside of our control area.
- We have been working very hard to create service features that will reduce these transmission costs.
- Developments include capping the redelivery volumes at 50% of the project's nameplate rating and potentially using NT transmission for imports.

Capped Redelivery Volumes

- We have reduced the costs of transmission for the redelivered energy by capping the amount of power that we will redeliver at 50% of the nameplate rating of the project.
- During times when, say, a 100MW project generates above 50MW on average for a day, we will store the incremental energy above 50MW beyond the 1-week redelivery period. We will then draw down from this storage account during hours when the redelivery obligation is less than 50MW.
- This reduces the amount of transmission that must be reserved for the wheel out and also increases its utilization factor, thus considerably reducing its cost. (For long-term transmission the cost is reduced by over 50%)

Importing on NT Transmission

- Most regional utilities use Network Transmission (not Point-to-Point) to import power into their systems.
- Since the costs of Network Transmission are already paid for (either by the merchant function or by native load), imports can be consummated at no incremental cost.
- BPA's Power Business Line has a more complicated relationship to Network Transmission than most regional utilities. BPA's power customers, rather than the Power Business Line itself, have the rights to NT transmission.
- We have an agreement in place with a large group of our customers that allows us to use their NT transmission rights to import power into our system on a non-firm basis. Combined with capped redelivery volumes, this could reduce the cost of S&S Service to as low as \$10.50/MWh delivered.
- The NT agreement has some excellent features – flexibility, no incremental cost. But it expires in 2011 and it is non-firm.

Importing on NT Transmission

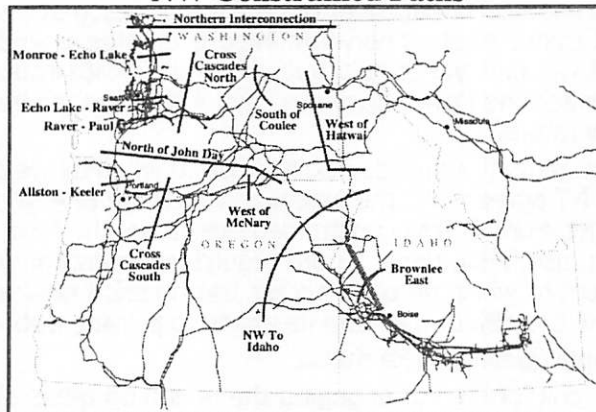
- The short-term nature of our NT transmission access and the fact that it involves non-firm imports creates a series of risks that we have yet to fully quantify and allocate equitably between the Power Business Line, interested utilities and wind generators.
- Ultimately, the question boils down to whether we can extend the NT agreement, the extent to which the BPA grid is going to get more or less constrained over time, the form and cost of transmission under future regulatory environments, and the extent to which an open access transmission environment will allow the PBL to maintain its ability to provide public benefits.
- Simple questions like that...
- We look forward to engaging the region on these difficult and important questions and crafting a strategy that works for BPA and regional stakeholders.

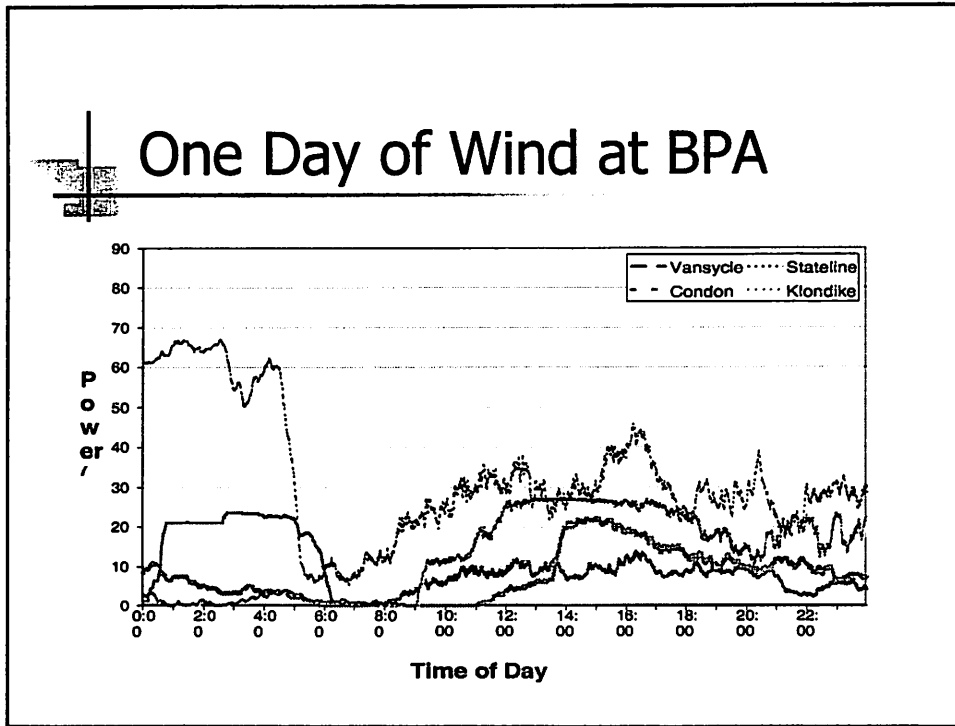
Contact Information

Elliot Mainzer
 Manager, Pricing and Transaction Analysis
 Bonneville Power Administration
 PO Box 3621
 Portland, OR 97208
 (503) 230-3530
eemainzer@bpa.gov

Transmission Availability a Potential Problem

NW Constrained Paths







Wind & Hydropower Technologies Program

The Wind/Hydropower Connection to Hydrogen:
Report on the
*Workshop on Electrolysis Production of
Hydrogen from Wind and Hydropower,*
Held on September 9, 2003 in Washington, DC

IEA Wind/Hydropower Integration Experts Meeting
Portland, Oregon, USA

Patrick Quinlan
National Renewable Energy Laboratory
Wind and Hydropower Technologies
Washington DC, USA



Workshop Agenda

- Presentations: Introduction, current status of technologies and issues.
- Open Discussion Session on a Sample Wind/Hydro Hydrogen Vision.
- Presentations on Wind-Hydrogen Modeling Efforts.
- Discussion of Modeling Efforts and Industry Feedback.
- Facilitated Sessions on Challenges, R&D Needs and Priorities:
 - Session 1: What are the challenges/barriers (both technical and non-technical) to achieving the vision(s)?
 - Session 2: What R&D or other activities are needed to overcome these barriers?
 - Session 3: Review and discuss results. Identify the role of the Federal government for top-priority activities.
- Conclusions and Next Steps.



Workshop Participants

Fifty Participants:

Feds: DOE/Wind, DOE/Hydropower, DOE/Hydrogen, NREL

Wind: Vestas, GE, Northern Power, Wintec,

Hydropower: National Hydropower Association, Southern Co., Xcel Energy, Grant County PUD, Safe Harbor Water Power

Hydrogen: Stuart Energy, Proton Energy, Wind Hydrogen Ltd. (UK),

Consultants: Sentech, Energetics, Polansky, ISE Research

Stakeholders: EPRI, MPIRG, Leighty Foundation.

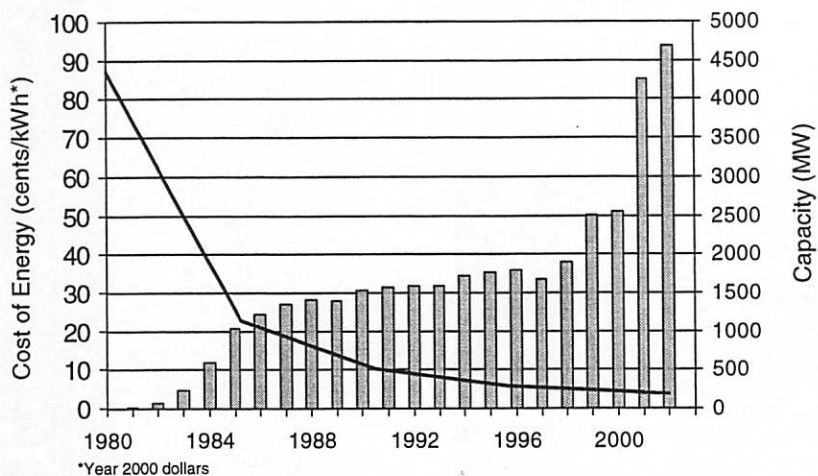
SourceOne Capital



Presentation Highlights



U.S. Wind Power Cost, Capacity Trends (Goldman)

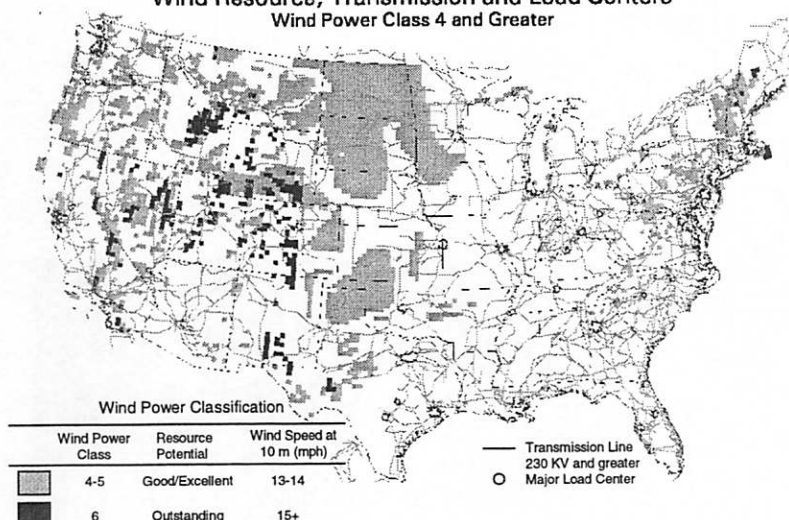


Increased Turbine Size - R&D Advances - Manufacturing Improvements



Low Wind Speed Opportunity (Goldman)

Wind Resource, Transmission and Load Centers
Wind Power Class 4 and Greater

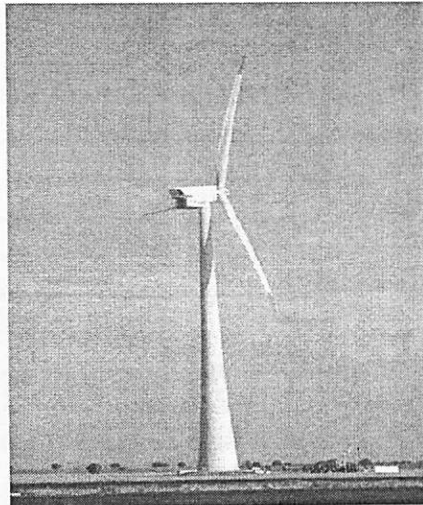
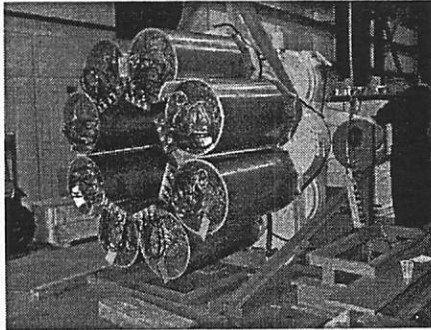




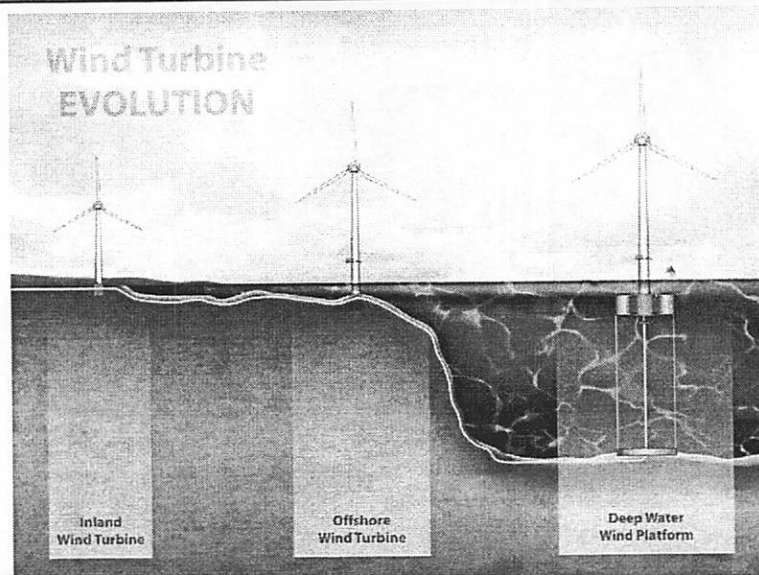
Low Wind Speed Technology Development (Goldman)

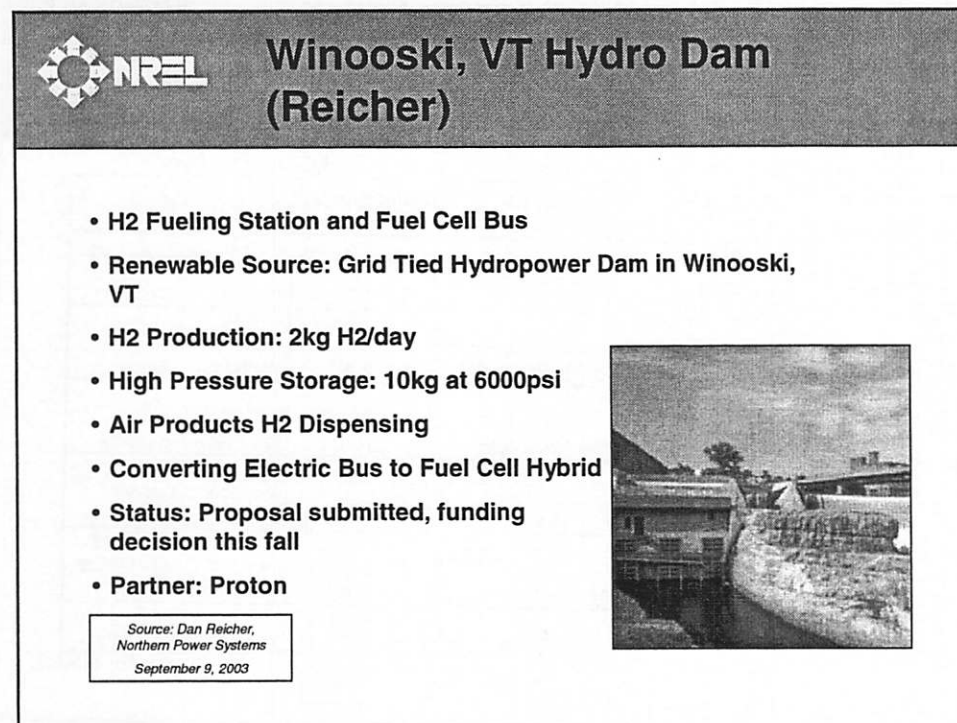
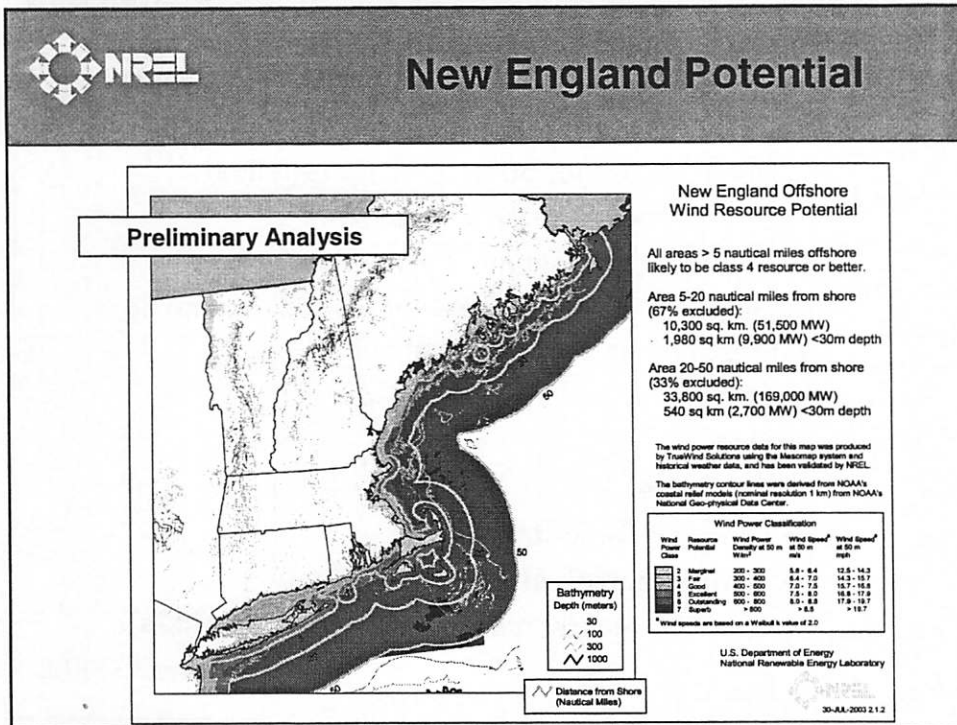
Large Systems (> 100 kW)

By 2012, reduce COE from large systems in Class 4 winds 3 cents/kWh onshore or 5 cents/kWh offshore



Deep Water Potential (Goldman)







If Half of the Vehicles Were HFCV...(Reicher)

- Hydrogen required for 50% of the current fleet
 - Approximately 40 million tons/year
 - Assumed 2x improvement in efficiency
 - Calculated the resource requirements, assuming the resource is only one available
 - Natural gas
 - Coal
 - Biomass
 - Solar (PV)-electrolysis
 - Wind-electrolysis
 - Nuclear-electrolysis (not chemical cycles)

Source: NREL



Hydrogen Energy Resource Requirements (Reicher)

Domestic resources required to produce H₂ for 50% of US vehicle fleet*

Resource	Needed for H ₂	Availability	Current Consumption	Increase in Consumption	Footprint
Chemical Reforming					
Natural Gas	95 million tons/year	28 billion tons	475 million tons/year	1.2	600 dedicated plants
Biomass	400-800 million tons/year	800-1100 million tons/year	200 million tons/year	2-4	400-600 dedicated plants
Coal	283-566 million tons/year	4 trillion tons	1100 million tons/year	1.2 - 1.3	225 dedicated plants
Water Electrolysis					
Wind	555 GW	3250 GW	4 GW	140	Available capacity of North Dakota
Solar	740 GW	>>5000 GW	< 1 GW	>740	3750 sq. miles (same as White Sands Missile Range, NM)
Nuclear	216 GW	n/a	98 GW	2.2	140 dedicated plants

*Source: NREL



Costs of Electricity vs. NG for H2 Production (Reicher)

\$ of electricity to produce 1kg of H2*

\$/kWh of electricity	Electrolyzer Efficiency (LHV of H2)		
	50%	70%	90%
\$0.06	\$3.98	\$2.85	\$2.21
\$0.04	\$2.66	\$1.90	\$1.48
\$0.02	\$1.33	\$0.95	\$0.74

\$ of NG to produce 1kg of H2*

\$/MMBtu	Reformer Conversion Efficiency (LHV H2 / LHV NG)		
	50%	70%	90%
\$12.00	\$2.74	\$1.95	\$1.52
\$8.00	\$1.82	\$1.30	\$1.01
\$4.00	\$0.91	\$0.65	\$0.51

* Capital, O&M, storage, and delivery costs not included

Source: Dan Reicher,
Northern Power Systems
September 9, 2003

greater than \$2.00/kg

less than \$2.00/kg

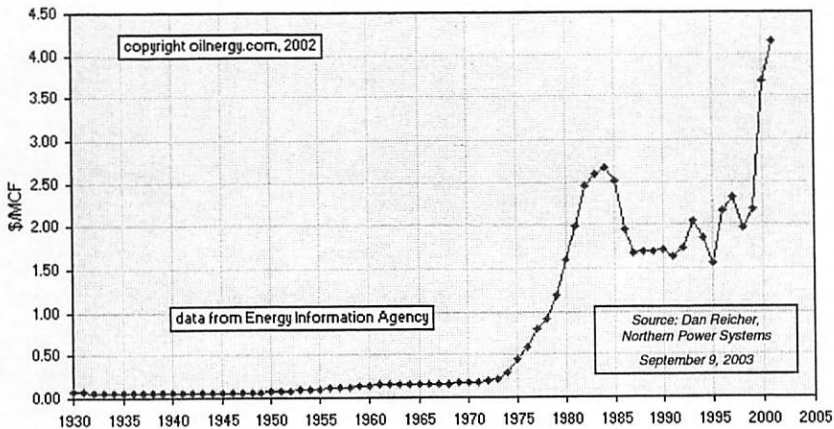
Conversions


114,000 btu/gal of gasoline (LHV)	33.2 kWh/gal gasoline
3,412 btu / kWh	1.0 kg H2/gal gasoline



Natural Gas Prices (Reicher)

U. S. Wellhead Natural Gas Price





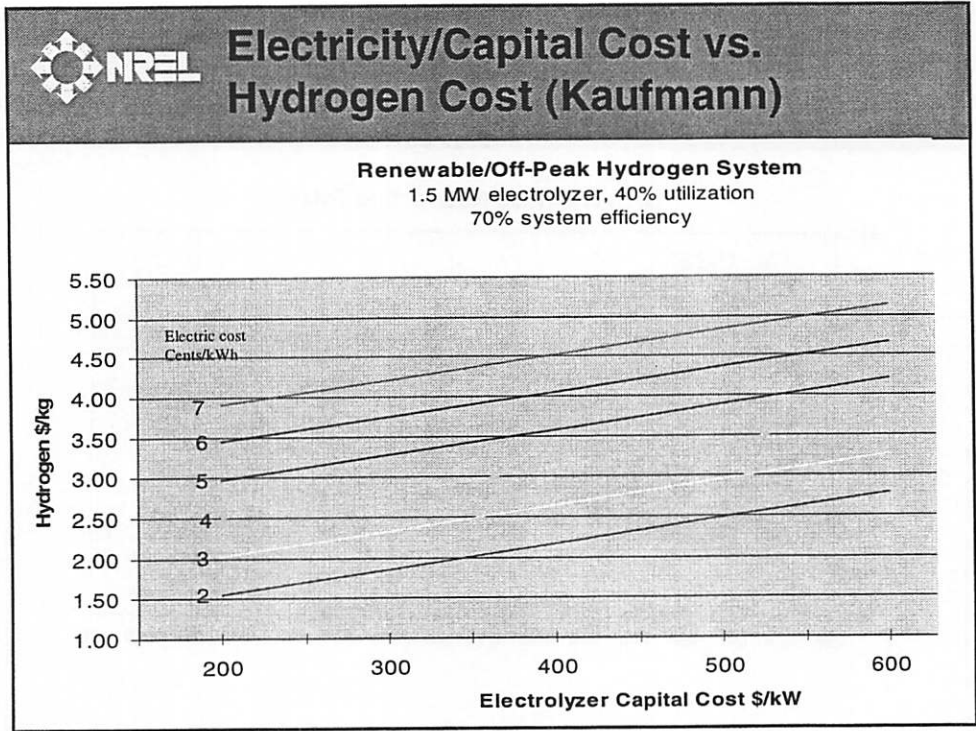
Cost Target Implications (Fairley)

▪ Simple Cost Model :

Source: Mathew Fairley, Stuart Energy Sept. 9, 2003

- $\$/\text{kg} = \text{Efficiency} * (\text{price of electricity}) +$
 $[\text{Annual (CRF+O/M)}] * (\text{Capital Cost per kg/h}) \div [(\text{capacity factor}) * 8760 \text{ h/y}]$
- Implications
 - For Annual (CRF +O/M) =20%
 - Capacity Factor = .35
 - Avg. Efficiency = 50 kWh/kg (=approx 80% wrt HHV)

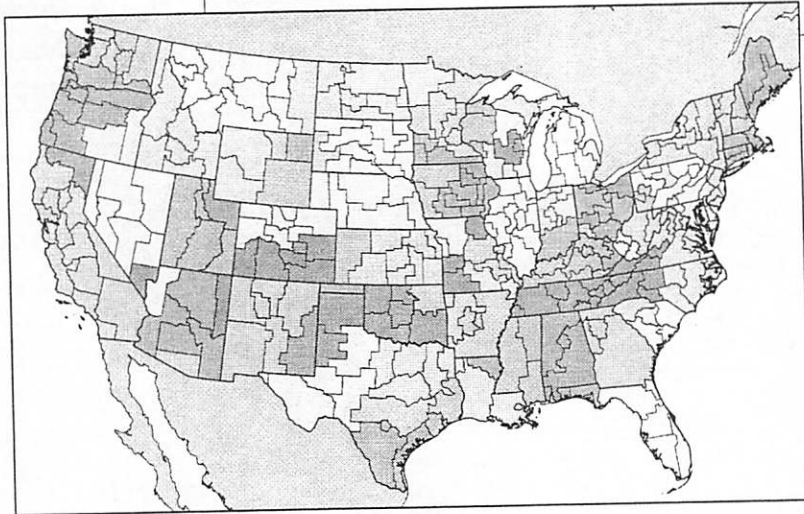
Cost of Wind Electricity	2.5 ¢/kWh	3.0 ¢/kWh
Cost of Electrolyser (@ Avg Efficiency)	\$12,000/kg/h	\$8,000/kg/h





NREL: WinDS and WindStorm Models (Short, Fingersh)

WinDS PCA and Demand Regions



Wind/Hydro Hydrogen Production Modeling (Mann)

WinDS and WinDS-H2

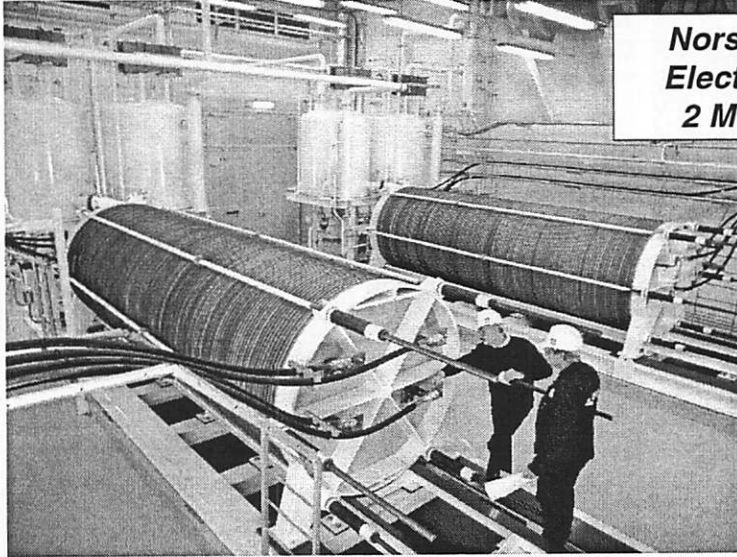
- When and where? and \$\$\$?
- Purpose: Address principle market issues for wind and wind/H₂
- Access to and cost of transmission
- Impact of hydrogen on intermittency
- 358 regions, GIS-supported
- Electricity transmission, H₂ storage, H₂ fuel
- Future: SMR, hydro, biomass

WindSTORM

- \$\$\$? and Hybrid?
- Purpose: optimize interface between wind turbine and H₂ components (electrolyzer, fuel cell, energy storage)
- Effect of control strategy on system cost
- H₂ used to store electricity or sold as fuel
- Shared power conversion, in-tower compressed gas storage, Ni-H₂ 'battery'



Electrolyzers (Leighty)

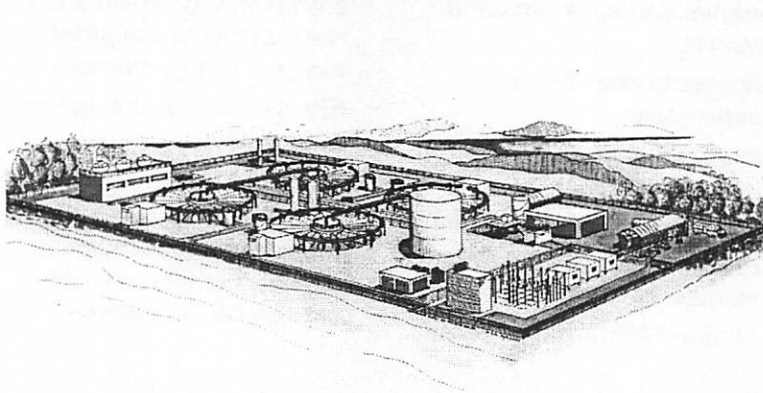


*Norsk Hydro
Electrolyzers
2 MW each*



Norsk Hydro Electrolyzer (Leighty)

*Norsk Hydro Complete Electrolyzer Plant, KOH (proposed)
265 MWe capacity, \$570 / kWe, 70% efficiency*





The Workshop: Key Drivers

Coupling wind and hydropower to low-cost electrolyzers can potentially:

- Provide additional incentives and synergies for co-located wind and hydropower facilities (e.g., to improve wind capacity factors)
- Improve electrical power system dispatchability and balance transmission loads
- Provide options for optimizing outputs of “products” (electricity and/or hydrogen) based on site-specific energy demand and cost factors
- Provide innovative opportunities for off-peak energy storage (e.g., use of a wind turbine tower to store hydrogen or hydro pumped storage systems)



Wind/Hydropower Electrolysis --Uncertainties

- Capability to produce electricity at a cost that would enable bulk production of cost-competitive hydrogen currently estimated at 2 to 3.5¢/kWh
- Need to lower electrolyzer capital costs
- Need for optimal system configuration designs
- Need to resolve power system integration issues at local, regional and national levels



Workshop Purpose

- Begin a dialogue among representatives from the wind turbine, hydropower, and electrolysis industries
- Gather industry feedback on current modeling and analysis efforts funded by DOE on the potential for co-production of electricity and hydrogen from wind and hydropower.
- Facilitate industry input on:
 - key challenges to electrolysis production of hydrogen from wind and hydropower
 - research and development (or other) activities needed to address these challenges.



Workshop Results

- Draft Vision and Comments: "Role of Wind and Hydropower in Hydrogen Production."--near-term (now through 2015), and long term (2030 onward).
- Comments on DOE/NREL Modeling Activities:
 - WinDS-H2 <http://www.eere.energy.gov/hydrogenandfuelcells/hydrogen/wkshop-wind-hydro.html>
 - WindSTORM <http://www.eere.energy.gov/hydrogenandfuelcellshydrogen/wkshop-wind-hydro.html>
- Results of Facilitated Sessions on Grand Challenges and R&D Needs
- Results of two facilitated discussion sessions on:
 - The key barriers to electrolysis production of hydrogen from wind and hydropower and
 - R&D needs (or other activities) required to overcome these barriers, including the lack of supporting infrastructure (hydrogen storage and delivery systems and electric transmission issues).



Next Steps

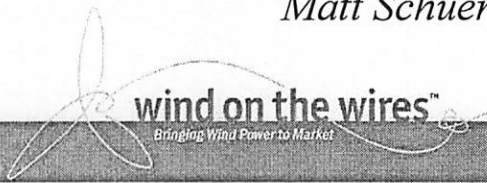
Next steps were identified around each of the workshop's three goals:

1. DOE will pursue the recommendation to form an industry working group to further synthesize the results of this workshop and to develop recommendations for future activities.
2. Comments received on NREL modeling and preliminary results will be incorporated, with results made available to the DOE Hydrogen Analysis (H2A) team.
3. Input from workshop participants will be used to shape ongoing DOE RD&D, with possibly a second workshop in 2004 to provide more detail on specific opportunities.



Wind-Hydro Integration In the Missouri Basin

*IEA Wind/Hydro Meeting
November 5-6, 2003
Matt Schuerger, P.E.*



www.windonthewires.org

Wind-Hydro Integration in the Missouri Basin

- ❖ New study, just getting underway
- ❖ Assess technical, economic, and institutional opportunities (and barriers) to utilizing hydro generation facilities on the Missouri River system to increase the amount of wind generation capacity in the upper Midwest, including potential to:
 - reduce ancillary service costs
 - increase overall economic and environmental value of power delivered
 - provide Missouri River management flexibility



www.windonthewires.org

Midwest Wind Power Development

	Wind Power (nameplate), MW			
	Existing ¹	Total Potential ²	% of State Consumption in 2010 ³	
			5%	10%
Iowa	423	62,900	779	1,558
Minnesota	401	75,000	1,120	2,240
Nebraska	14	99,100	452	903
North Dakota	66	138,400	183	366
South Dakota	44	117,200	156	313
Wisconsin	53	6,440	1,309	2,617
Total	1,001	499,040	3,999	7,997

Notes:

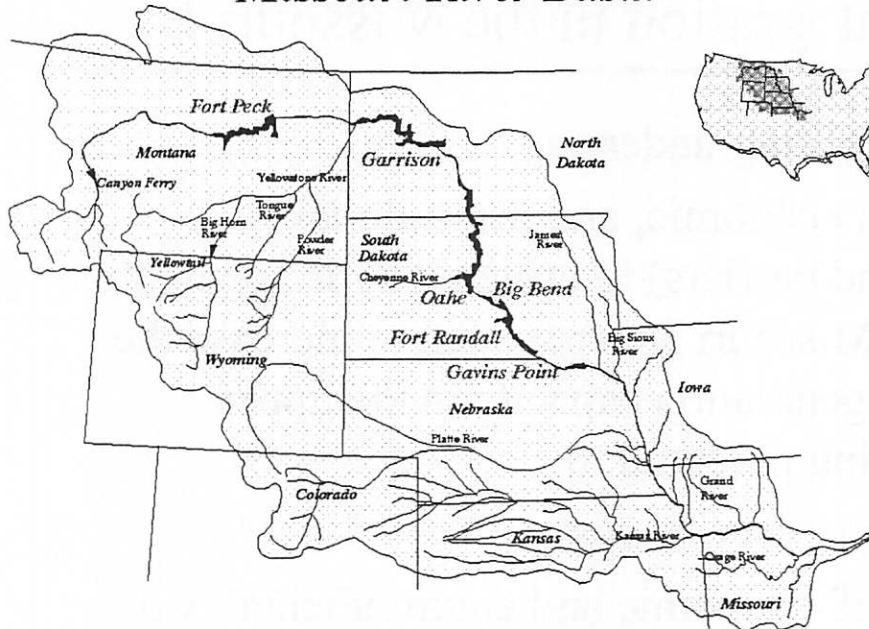
1. American Wind Energy Association, October 2003, <http://www.awea.org/>
2. Avg MW, *An Assessment of Windy Land Area and Wind Energy Potential*, Pacific Northwest Lab, 1991.
3. Wind power capacity equivalent.
Energy Information Administration, 1999, <http://www.eia.doe.gov/emeu/states/states.html>

wind on the wires™

Bringing Wind Power to Market

www.windonthewires.org

Missouri River Basin



❖ Six dams, 2500 MW capacity (nameplate)

❖ Combined storage 75 million acre-feet (93 billion m³), about 3 times average annual runoff

❖ Operated by Corp of Engineers

❖ Marketed by Western Area Power Administration

wind on the wires™

Bringing Wind Power to Market

www.windonthewires.org

Western Area Power Administration

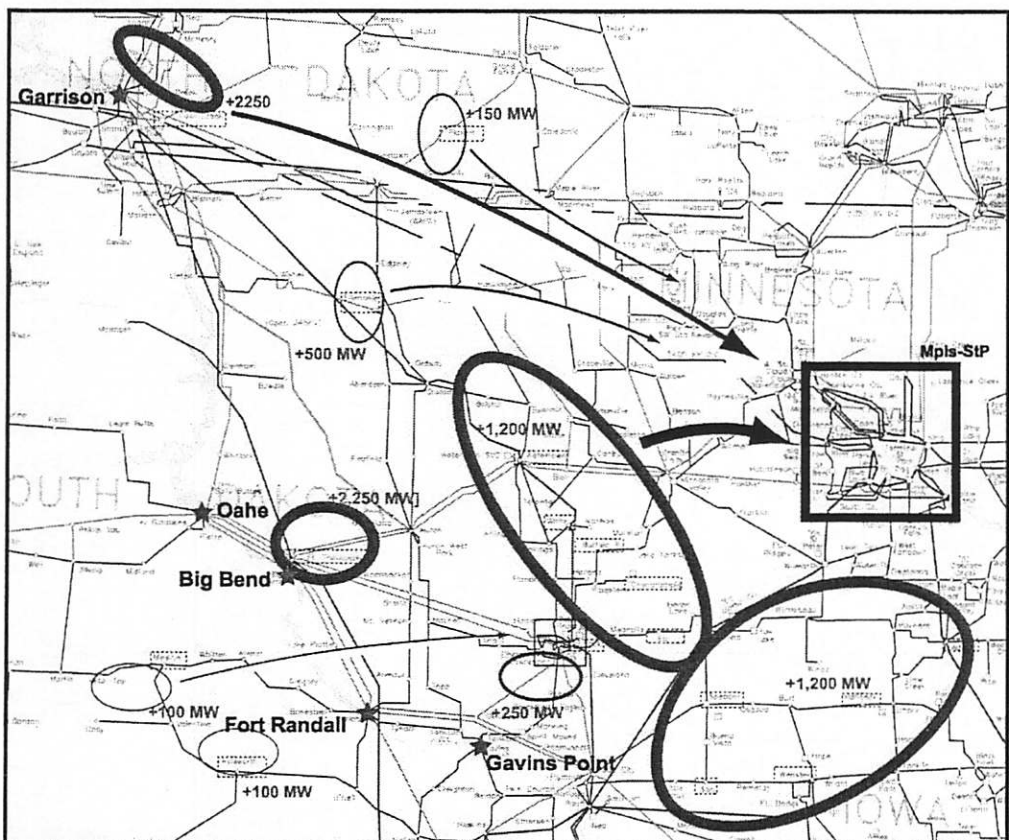
- ❖ One of four power marketing administrations within the U.S. Department of Energy
- ❖ Markets and transmits federally produced hydroelectric power
- ❖ Approximately 3300 MW of load and 2000 MW thermal generation
- ❖ Western's 636 wholesale power customers include cooperatives, municipalities, public utility districts, and project use customers.



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Existing hydro power (stars) and Projected wind power (ellipses)



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Issues include:

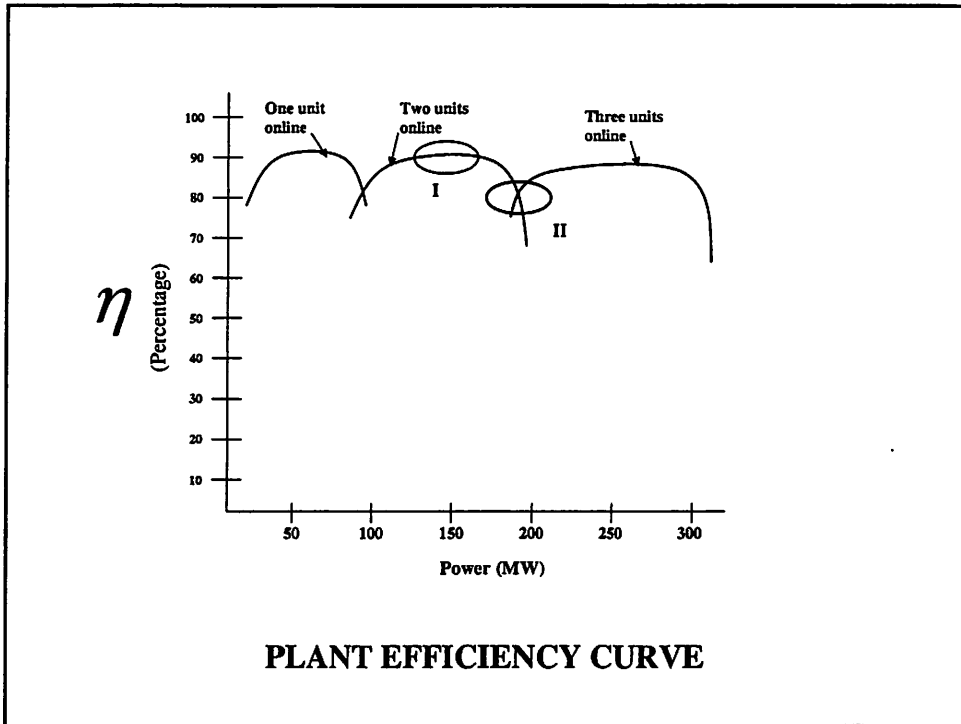
- ❖ **Competing purposes for the Missouri River System**
(fish & wildlife, flood control, recreation, irrigation, water supply & quality, navigation, and hydro power)
- ❖ **Increasing operational constraints**
(endangered species, ice jams, changes in Master Manual, increases in reserve requirements)
- ❖ **Existing, long term Preference Power contracts**
(cooperatives, municipalities, Native American communities)
- ❖ **Inter-year variations in power production due to weather**

**HYDRO
OPTIMIZATION
AND EFFICIENCY IMPROVEMENTS**

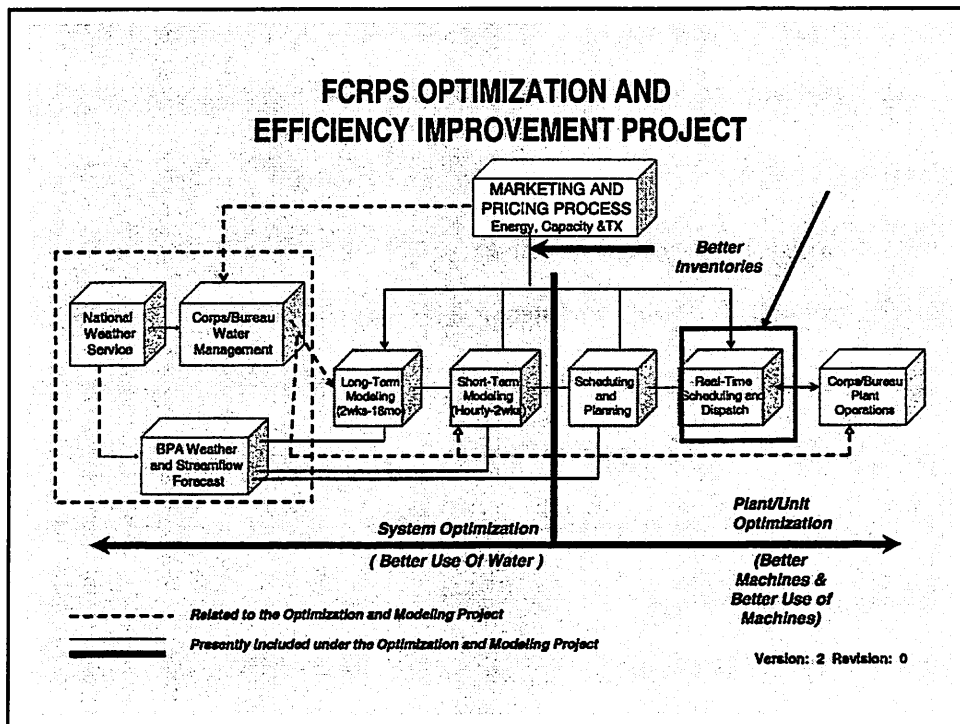
Tom Murphy

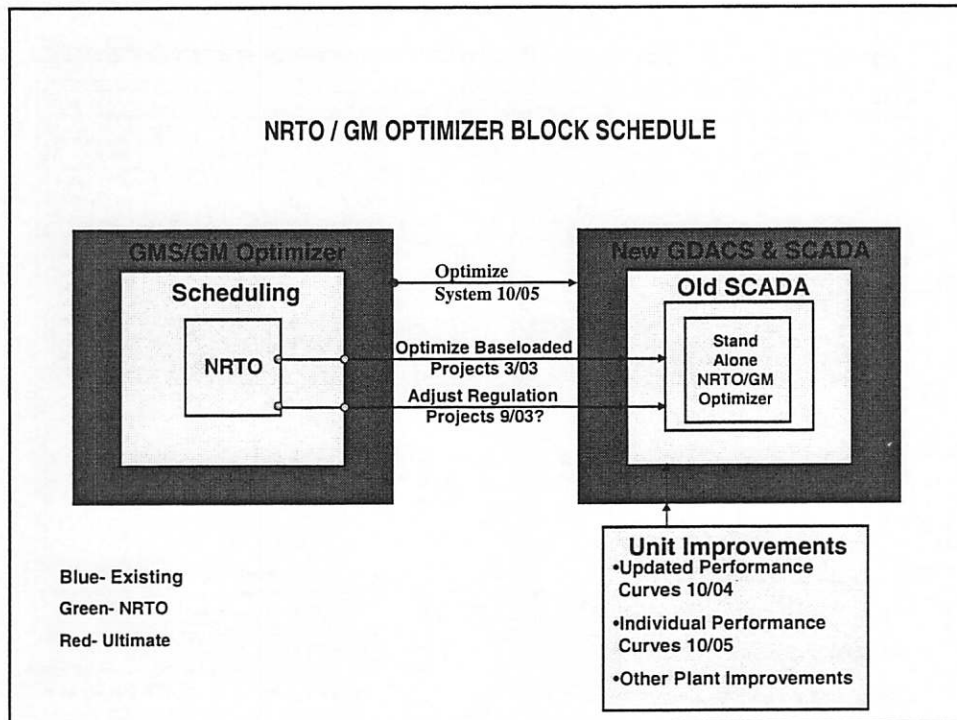
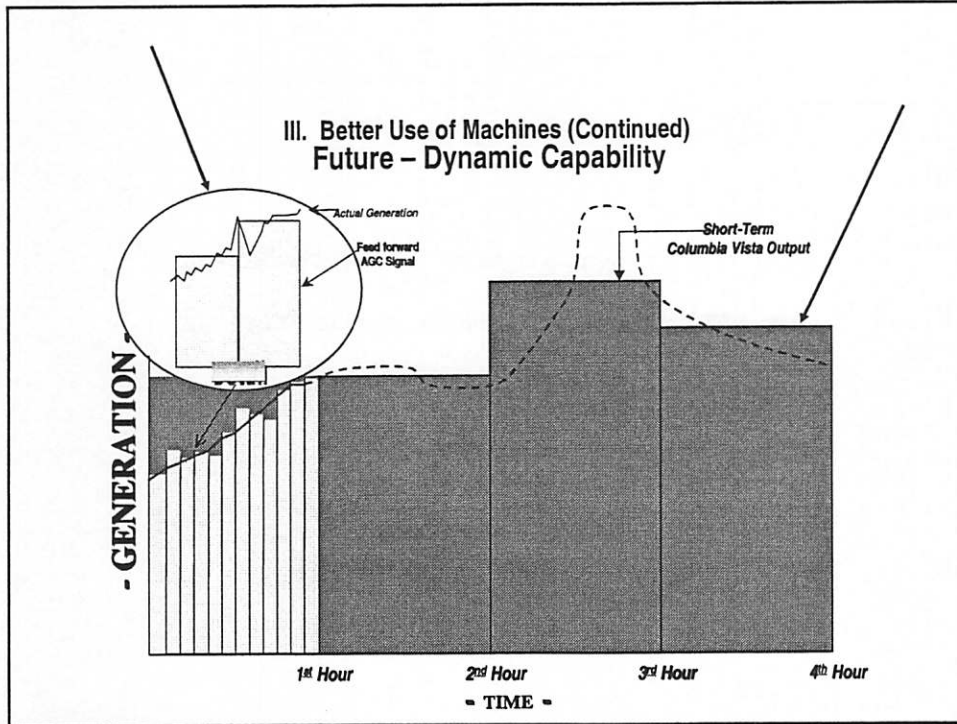
Goals and Scope

- ♦ **Better use of H2O (*Basin Optimization*)**
- ♦ **Better use of Machines (*Plant Optimization*)**
- ♦ **Better Machines (*Unit Optimization*)**
- ♦ **Better Inventory Management**



PLANT EFFICIENCY CURVE





Next Steps

- ♦ Test and Validate @ Corps and Reclamation Projects- FY 04
- ♦ Improve NRTO performance/ test simulation mode- FY 04
- ♦ Perform Operational Studies- FY 04
- ♦ Install as stand-alone @ Projects – FY 04/05
- ♦ Develop GM Optimizer- FY 04/05
- ♦ Connect/Install to Project SCADA systems- FY 05/06

Lost generation before basepoint optimization

Project	Current Loading [MW]	Calculated Basepoints [MW]	Loading Change [MW]	Adjusted Generation		HCRD Bias [MW]	Adjusted Federal Request Basepoints with Bias [MW]	Optimal Output - Generation [MW]	Lost Generation [MW]	1% Efficiency Generation Limits		Percent Response Factors	
				Target [MW]	Result [MW]					Lower [MW]	Upper [MW]	User Selected	Model Selected
Total	7586	7414	0	7161	7161	-253	7414	1480	372	601	3189	100.00	100.00
Grand Coulee	2594	2594	0	2309	2309	-285	2584	1482	330	1117	2002	50.00	39.73
Chief Joseph	1486	1350	0	1352	1352	2	1350	125	6	-26	325	25.00	20.91
Lower Granite	95	95	0	95	95	0	95	-1	0	-13	60	0.00	0.00
Little Goose	90	90	0	90	90	0	90	43	2	3	65	0.00	0.00
Lower Monume	99	98	0	98	98	0	98	36	1	-4	57	0.00	0.00
Ice Harbor	70	70	0	70	70	0	70	13	1	0	29	0.00	0.00
McNary	682	682	0	682	682	0	682	-172	18	-216	-100	0.00	8.82
John Day	1054	1050	0	1050	1050	0	1050	64	1	-63	500	15.00	12.70
The Dalles	842	840	0	840	840	0	840	-41	1	-113	175	10.00	9.99
Bonneville	574	575	0	575	575	0	575	-69	12	-84	76	0.00	7.84

Main/In Same Unit Commitment
 Generation Limits
 Percent Response
 Total Load Change: Distribute
 System Spinning Reserve Target:
 Absolute Limits
 User-Selected
 Energy Value: \$ / MWh
 Total System Spinning Reserve:
 Relative to Adjusted Base Points
 Model-Selected
 SR Targets Set on Projects? No

Status: **Duty Scheduler** | Grand Coulee | Chief Joseph | Lower Granite | Little Goose | Lower Monumental | Ice Harbor | McNary | John Day | The Dalles | Bonneville
 Ready | Connected to post2.basat_hsp as tme9375 | Current Time: 13:51:36 | Base Time (Duty Scheduler): 13:00:00 | Base Time (Project Operator): 13:50:00 | Refresh Input
 Start | Windows | Inbox - M... | Calendar... | Datasets... | Microsoft... | 1:52 PM

Basepoints have been adjusted Solution assume number of units on line has not changed

Dataset: default - Near Real-Time Optimizer

File Edit View Tools Help

Output | Flow | Reserves | Load Trends

Project	Current Loading [MW]	Calculated Basepoints [MW]	Loading Change [MW]	Adjusted Generation		HCRD Bias [MW]	Adjusted Federal Basepoints [MW]	Optimal Output - with Bias [MW]	Lost Generation [MW]	1% Efficiency Generation Limits		Percent Response Factors	
				Target [MW]	Result [MW]					Lower [MW]	Upper [MW]	User Selected	Model Selected
Total	7586	7414	0	7161	7161	-253	7414	8541	319	7762	10350	100.00	100.00
Grand Coulee	2594	2564	00	2389	2389	-256	2644	3791	294	3426	4311	50.00	39.73
Chief Joseph	1486	1350	0	1352	1352	2	1350	1477	8	1326	1677	25.00	20.91
Lower Granite	95	95	0	95	95	0	95	94	0	82	155	0.00	0.00
Little Goose	90	90	10	100	100	0	100	133	1	93	155	0.00	0.00
Lower Monumental	99	98	5	103	103	0	103	134	1	94	155	0.00	0.00
Ice Harbor	70	70	13	83	83	0	83	83	0	70	99	0.00	0.00
McNary	662	682	-14	668	668	0	669	510	17	466	582	0.00	8.82
John Day	1054	1050	16	1066	1066	0	1066	1114	0	987	1550	15.00	12.70
The Dalles	842	840	-41	799	799	0	799	799	0	727	1015	10.00	9.99
Bonneville	574	575	-69	506	506	0	506	506	0	491	651	0.00	7.84

Solution assume number of units on line has not changed

Maintain Same Unit Commitment
 Operating Limits: System Spinning Reserve Target: 0
 Cavitation: 0
 Generation Limits: Absolute Limits
 Percent Response: User-Selected

Total Load Change: 0
 Energy Value: 45 \$ / MWh
 Total System Spinning Reserve: 4911
 SR Targets Set on Projects?: No
 Relative to Adjusted Base Points
 Model Selected

Status: Duty Scheduler | Grand Coulee | Chief Joseph | Lower Granite | Little Goose | Lower Monumental | Ice Harbor | McNary | John Day | The Dalles | Bonneville

Ready | Connected to post2_base_opt as tm9375 | Current Time: 14:24:22 | Base Time (Duty Scheduler): 13:00:00 | Base Time (Project Operator): 13:50:00

Windows | Inboxes | Calendar | Datasets | Microsoft

Solution assume number of units on line has changed

Dataset: default - Near Real-Time Optimizer

File Edit View Tools Help

Output | Flow | Reserves | Load Trends

Project	Current Loading [MW]	Calculated Basepoints [MW]	Loading Change [MW]	Adjusted Generation		HCRD Bias [MW]	Adjusted Federal Basepoints [MW]	Optimal Output - with Bias [MW]	Lost Generation [MW]	1% Efficiency Generation Limits		Percent Response Factors	
				Target [MW]	Result [MW]					Lower [MW]	Upper [MW]	User Selected	Model Selected
Total	7586	7414	0	7161	7161	-253	7414	6716	28	5941	8040	100.00	100.00
Grand Coulee	2594	2564	00	2389	2389	-256	2644	2298	3	2014	2691	50.00	39.73
Chief Joseph	1486	1350	0	1352	1352	2	1350	1328	0	1189	1586	25.00	20.91
Lower Granite	95	95	0	95	95	0	95	94	0	82	155	0.00	0.00
Little Goose	90	90	10	100	100	0	100	133	1	93	155	0.00	0.00
Lower Monumental	99	98	5	103	103	0	103	134	1	94	155	0.00	0.00
Ice Harbor	70	70	13	83	83	0	83	83	0	70	99	0.00	0.00
McNary	662	682	-14	668	668	0	669	510	17	466	582	0.00	8.82
John Day	1054	1050	16	1066	1066	0	1066	920	2	793	1240	15.00	12.70
The Dalles	842	840	-41	799	799	0	799	747	1	676	946	10.00	9.99
Bonneville	574	575	-69	506	506	0	506	473	3	464	682	8.00	7.84

Solution assume number of units on line has changed

Maintain Same Unit Commitment
 Operating Limits: System Spinning Reserve Target: 0
 Cavitation: 2262
 Generation Limits: Absolute Limits
 Percent Response: User-Selected

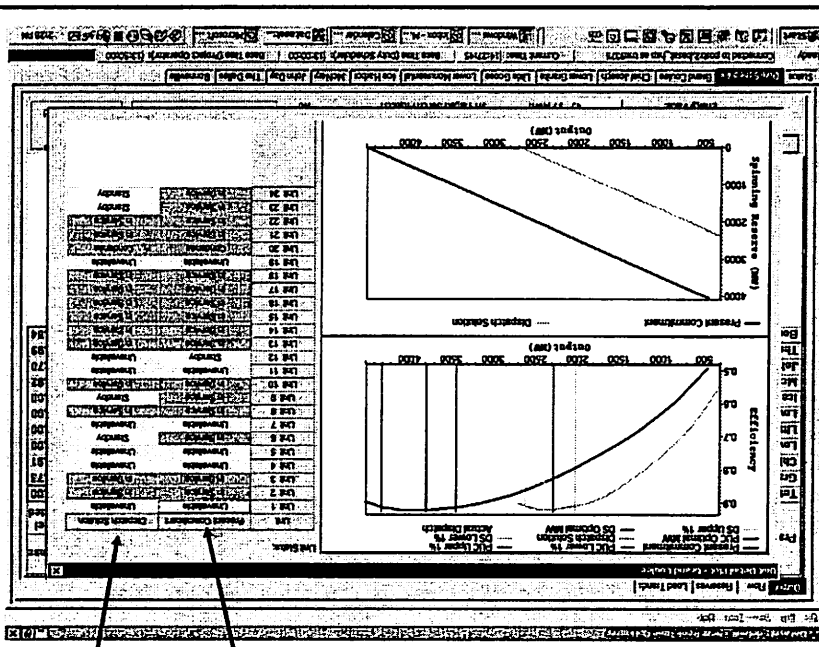
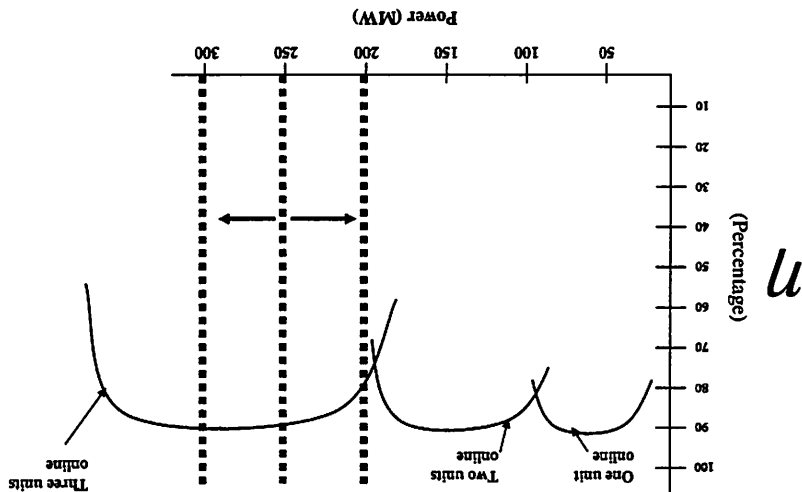
Total Load Change: 0
 Energy Value: 45 \$ / MWh
 Total System Spinning Reserve: 2262
 SR Targets Set on Projects?: No
 Relative to Adjusted Base Points
 Model Selected

Status: Duty Scheduler | Grand Coulee | Chief Joseph | Lower Granite | Little Goose | Lower Monumental | Ice Harbor | McNary | John Day | The Dalles | Bonneville

Ready | Connected to post2_base_opt as tm9375 | Current Time: 14:29:47 | Base Time (Duty Scheduler): 13:00:00 | Base Time (Project Operator): 13:50:00

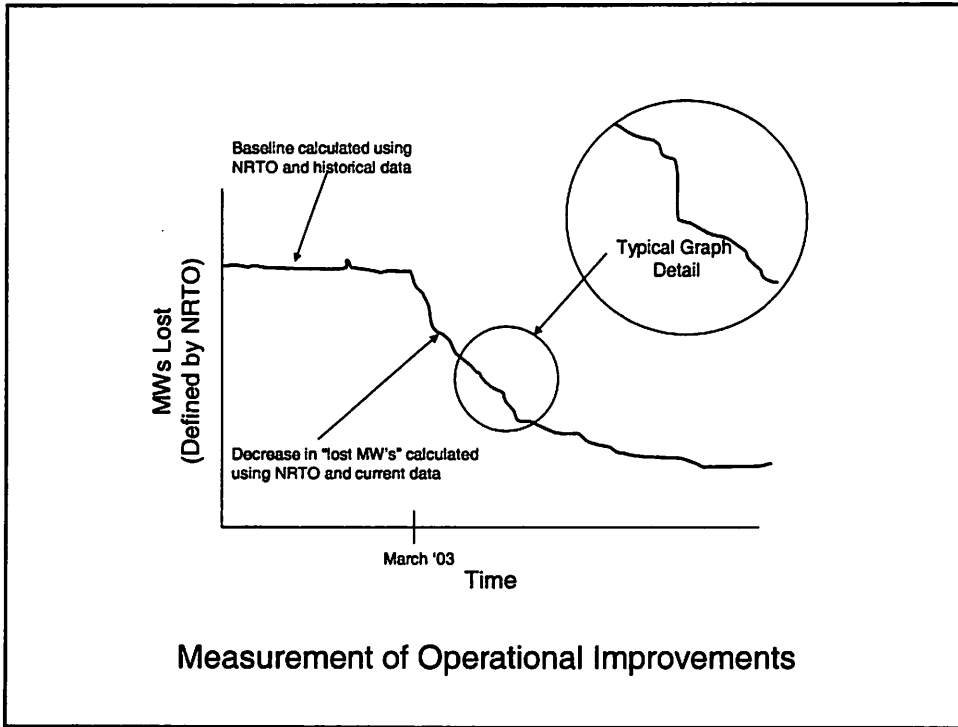
Windows | Inboxes | Calendar | Datasets | Microsoft

MOVEMENT ON THE PLANT EFFICIENCY CURVE



Does not change units on line

Changes units on line



WIND - HYDRO INTEGRATION IN NORWAY

John Olav Giæver Tande

SINTEF Energy Research
7465 Trondheim, Norway

Phone: +47 73 59 74 94; Fax: +47 73 59 72 50

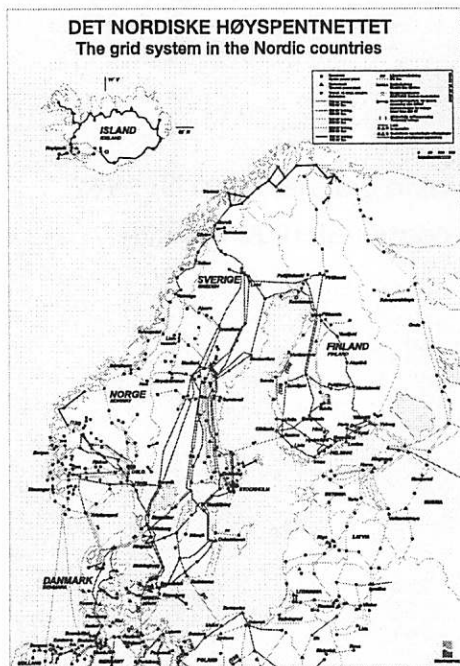
john.o.tande@sintef.no

Scope of presentation

- characteristics of hydro and wind generation in Norway
- possible system benefits by coordinated generation

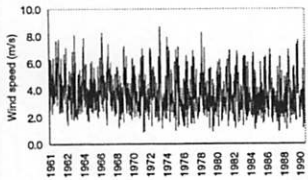
Norwegian power system

- Almost all production is from large hydropower plants
- Annual generation capability is about 118 TWh +/- 30 TWh
- Inland consumption in 2002 was 120 TWh
- Deregulated Nordic power market with spot prices varying from 0.10-0.30 NOK/kWh largely depending on hydro production capabilities (100 NOK ~ 13 USD)
- Difficult to obtain permission for new large hydropower plants, hence alternative sources as wind, bio and natural gas are getting attention, but also small scale hydro and upgrading of existing hydro plants
- The long coastline of Norway provides for excellent wind conditions
- The official target is 3 TWh of wind power by 2010, though the potential is much higher, could be 30 TWh or more
- Wind farm development has basically just started, 100 MW is installed, whereas about 7 TWh/year is in planning

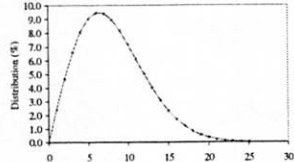


- Wind farms are planned in mainly along the coast of mid and north of Norway
- Wind power in Denmark covers about 15 % of the electricity consumption
- Significant wind power developments are planned also in Finland and Sweden

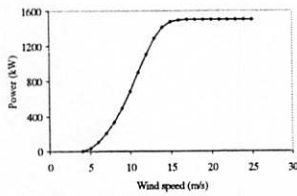
Calculation wind power time-series



■ Time-series from DNMI with wind speed v are transformed to:
 $T_a = 1$ week
 $T_u = 3000$ hours



■ $f_{i,j}(v)$: Rayleigh distribution of wind speed for week i in year j



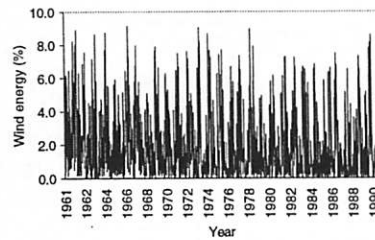
■ $P(v)$: Assumed power curve for wind turbine

■ Production in week i in year j :

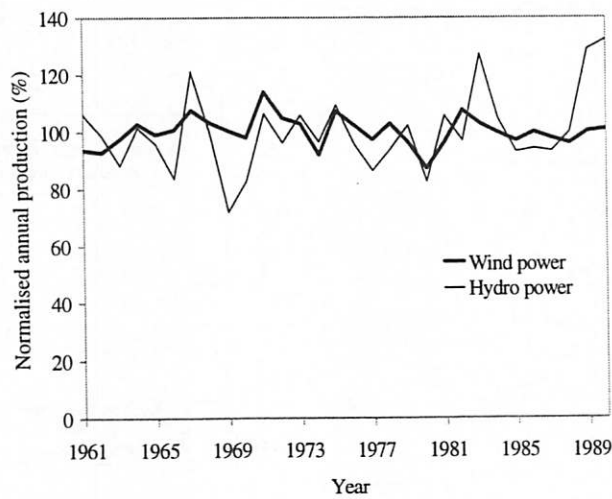
$$P_{i,j} = \int_0^{\infty} P(v) \cdot f_{i,j}(v) dv$$

■ Normalised production:

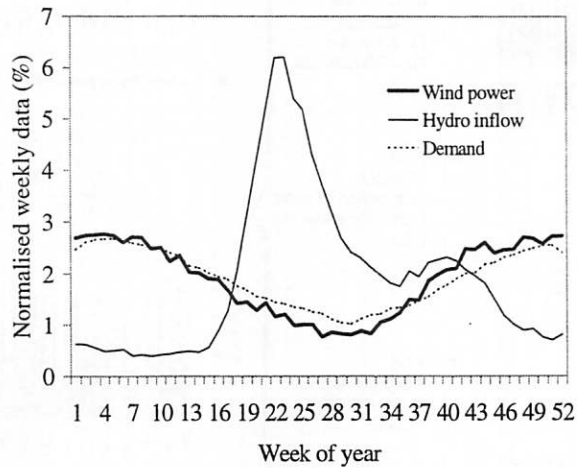
$$e_{i,j} = \frac{P_{i,j}}{\frac{1}{30} \cdot \sum_{j=1}^{30} \left(\sum_{i=1}^{N_j} P_{i,j} \right)}$$



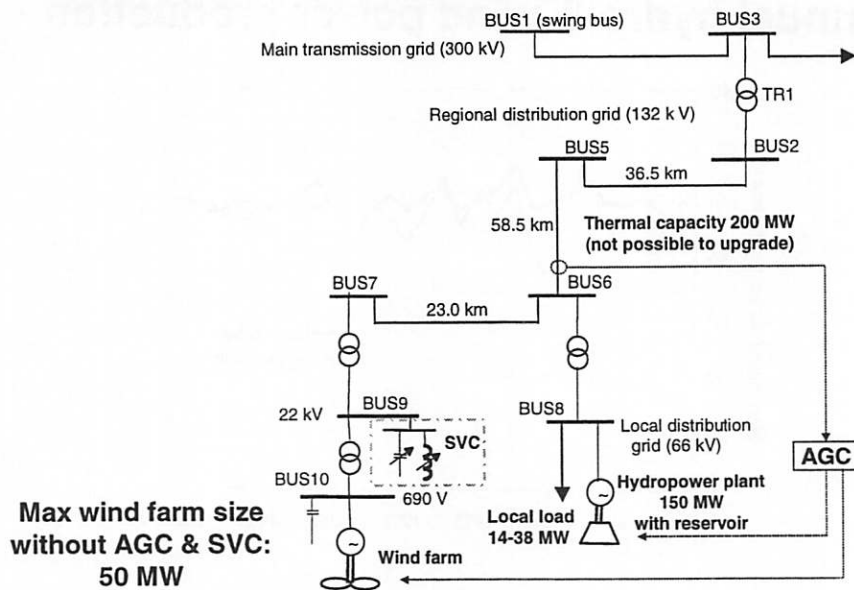
Annual hydro & wind power production



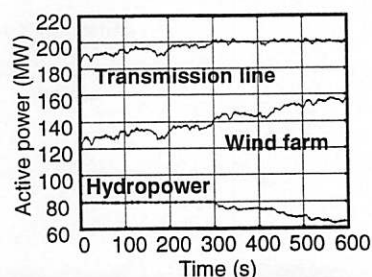
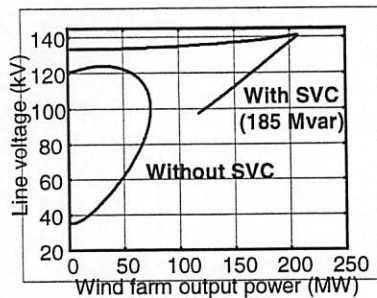
Weekly hydro inflow, demand and wind



Case study regional power system



Case study regional power system

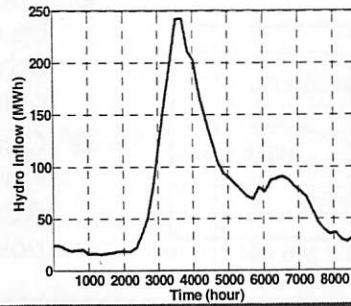
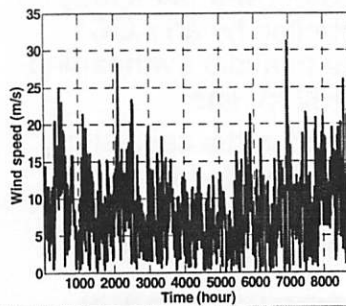
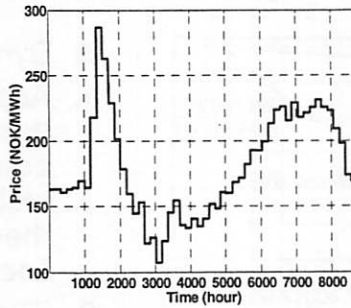
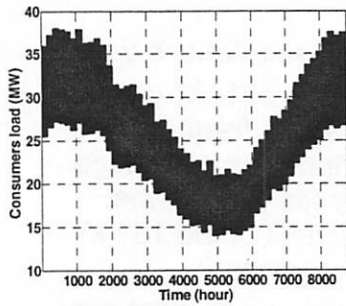


- Dynamic simulations verify:
 1. Application of SVC or wind turbines with frequency converters secure voltage stability (as long as the thermal limit of the 132 kV line is respected)
 2. The hydropower plant may be controlled by an AGC scheme to avoid overloading of the 132 kV line
- Question for this case study: How will the wind farm and AGC modify the regional power system operation?

Simulation model

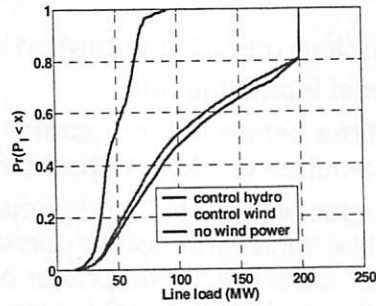
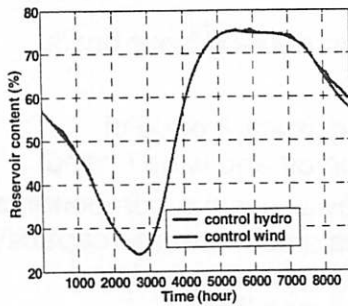
- Simulate one year operation on an hour-by-hour basis
- Model inputs includes:
 - time series with consumer load, market price of electricity, inflow to hydro reservoir and wind speed
 - specification of the regional power system components like wind farm power curve, maximum storage capacity of reservoir, rated power of hydropower plant and thermal limit of 132 kV transmission line
- Assumed AGC strategy:
 - The AGC operates to avoid line overloading
 - Control hydro: control the hydropower first and secondary the wind power (if needed)
 - Control wind: control the wind power only

Case study input time series data

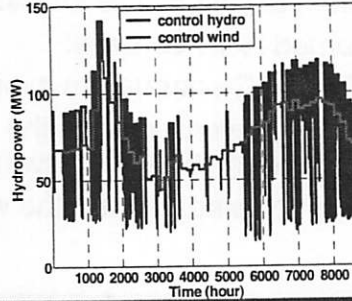
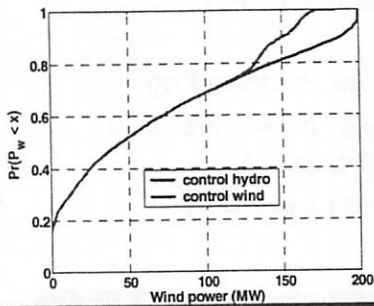


Annual inflow:
657 GWh
Storage capacity:
460 GWh

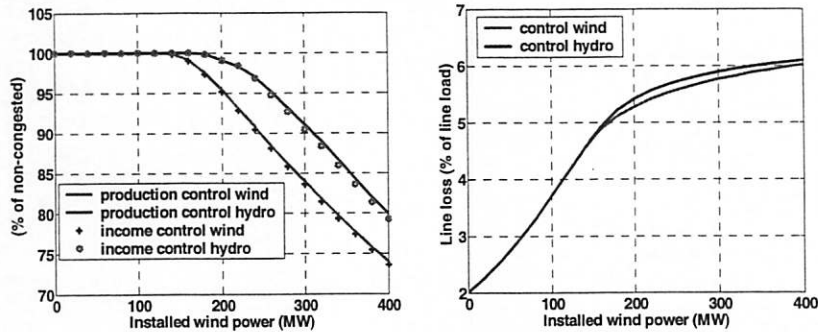
Simulation with 200 MW wind farm



Thermal limit:
200 MW



Simulation 0 - 400 MW wind farm



- Max wind farm size without AGC and reactive control: 50 MW
- AGC+SVC enables a 200 MW wind farm without severe losses
- AGC of hydropower provides for minimum energy losses
- AGC of wind farm only gives surprisingly low losses
- Significant line losses, but may not payback an upgrade
- Optimum size of wind farm depends on cost curve

Rounding up

- Good correlation between seasonal wind and load in Norway
- Seasonal hydro inflow is opposite to wind in Norway
- Integration studies indicate that with proper planning wind development in Norway may save hydro spillage
- Case study of connecting a wind farm to a regional power system with a weak link to the main grid shows that grid restrictions may be effectively relaxed by use of AGC and reactive control, and depending on technology & control the max wind farm size range from 50 to 200 MW

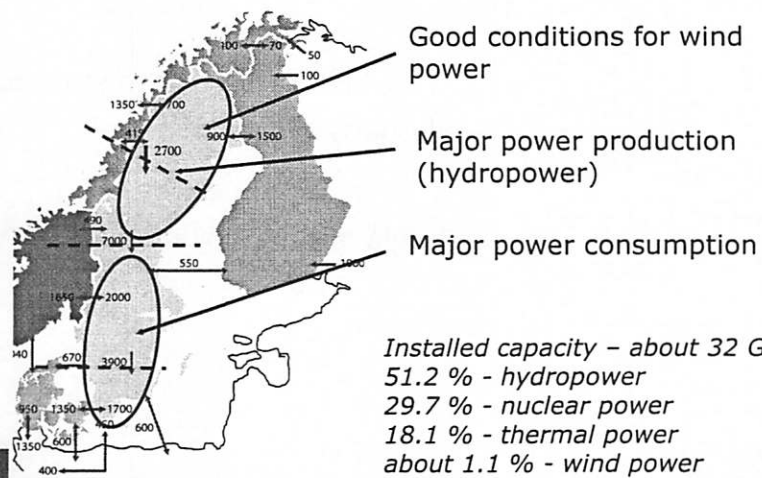
Evaluation of Wind Energy Storage in Hydro Reservoirs in Areas with Limited Transmission Capacity

Julija Matevosyan and Lennart Söder



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Problem formulation



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Problem formulation (cont)

New rules for connection of large-scale wind power to the transmission network require WPP to be able to decrease their production in case of congestion problems in the system

Transmission system reinforcement

The most effective alternatives are expensive and time consuming

Wind energy curtailment

Can be good alternative, in case of negative correlation between wind power production and power transmission

Storage in conventional power plants

Conventional power plants used for this purposes must be able to regulate their production fast



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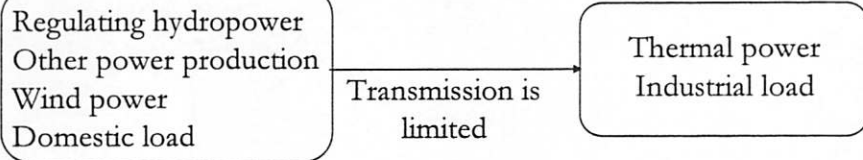
Main questions

- What are physical capabilities of HPP to store for wind power (based on historical data)?
- To what extent storage of excess wind energy may reduce wind energy curtailments?



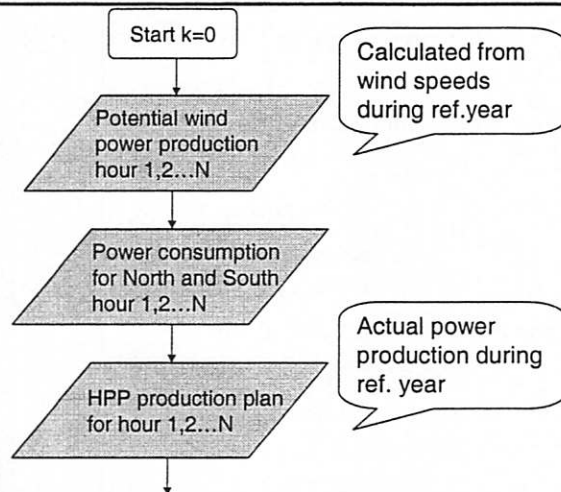
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Model for evaluation



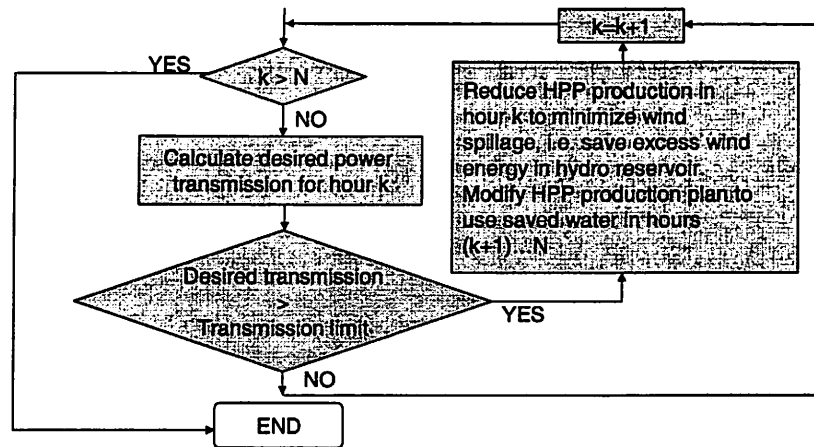
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Evaluation method (1)



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Evaluation method (2)



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Optimization problem

min (Costs for power production) - (Value of saved water)
 subjected to

1. Hydrological constraints
2. Reservoir and discharge limitations
3. Transmission limitation
4. Energy storage constraints

(total stored wind energy \leq potential wind energy curtailments)

5. Load balance constraints

(all load should be supplied)

6. Additional discharge constraint

(additional discharge \leq stored water)



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Results of the optimization

- Modified hydropower production including wind energy storage and disposal of saved water
- Modified wind power production (there still can be some curtailments)
- Reduced power production from other more expensive sources
- Better utilisation of existing transmission lines



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How can wind power be saved in hydro reservoirs in reality?

- If wind power plants owned by hydro utility it can be included in the production planning and regulated internally during the operation. The water saved because of wind power can be regarded as stochastic water inflow.



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How can wind power be saved in hydro reservoirs in reality?

Some ideas if hydro and wind not in same company

Assume hydropower decrease production because of transmission limit so that wind power can produce. But hydropower owners gets paid as if not decreased production. The stored water because of decrease then "belongs" to the wind power producer. How should this water be used?

- Water is disposed as soon as possible, i.e. the same day.
- Bid on spot market the next day.
- Water disposal optimized against spot price.
- Saved water is regarded as unexpected water inflow and disposal is planned as usual.



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Outline

1. Research project
 - i. Nordic power market
 - ii. Hydropower and wind power
 - iii. Problem description
2. Papers produced and under production
 - i. "Hydroplanning model including trade-off..."
 - ii. "Generating regulating power price scenarios"
3. Future work



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Future work

- Hydropower planning model for creating optimal bids to the regulating market, including a scenario tree.
- How will the stochastic behaviour of the regulating market be affected by increased amounts of wind power in the system?
- Consider the Elbas power market.



Evaluation of Wind Energy Storage in Hydro Reservoirs in Areas with Limited Transmission Capacity

J. Matevosyan, L. Söder, *Royal Institute of Technology*

Abstract— The best conditions for installation of wind power are often in the remote areas with low population density. The transmission system in such areas might not be dimensioned to accommodate large-scale power plants. Thermal limits of the conductors or voltage stability limits restrict transmission capability during the extreme situations such as for example low local loads and high wind power production. Substantial grid reinforcement is costly and time-consuming solution. Alternatively, excess wind energy can be curtailed during the congestion situations or stored. In this paper the possibility to use hydro reservoirs for storage of excess wind energy during congestion situations in the transmission system is evaluated. The suggested method allows us to analyse previous years of operation of the power system (e.g. dry, wet and normal year) and evaluate physical possibilities for wind energy storage.

I. NOMENCLATURE

A. Abbreviations

TSO	Transmission system operator
WF	Wind farm
HPP	Hydro power plant
he	hour equivalent, 1he = water flow of 1m ³ /s during one hour = 3600 m ³ /s
SEK	Swedish Krona ≈ 0.11 EUR (2003-09-25)

B. Sets

K	Set of indices for all hours in the in the evaluation period
K_c	Set of indices for hours when transmission is congested, $K_c \subset K$.
K_{nc}	Set of indices for hours when transmission is not congested, $K_{nc} \subset K$.
I	Set of indices of hydropower plants in the evaluation model
S_i	Set of indices of the segments of the production curve for plant i
Ω_i	Set of indices of plants directly upstream of plant i
Γ_i	Set of indices of plants downstream of plant i

C. Parameters

$\bar{P}_w(k)$	Maximum possible wind power production, hour k [MW].
$\bar{P}_{12}(k)$	Maximum transmission capacity, hour k [MW].

\bar{P}_s	Capacity of the slack source [MW].
$D_1(k)$	Load in area 1, hour k [MW].
$D_2(k)$	Load in area 2, hour k [MW].
c^e	Expected power price [SEK/MWh]
c^s	Cost of power from the slack source, more expensive than hydro or wind power [SEK/MWh]
\bar{u}_{is}	Maximum discharge in plant i , segment j [he]
\underline{u}_{is}	Minimum discharge in plant i , segment j [he]
μ_{is}	production equivalent for plant i , segment j [MWh/he]
γ_{is}	average production equivalent for plant i [MWh/he]
\bar{x}_{is}	Maximum reservoir content [he]
\underline{x}_{is}	Minimum reservoir content [he]
x_i^o	Initial reservoir contents [he]
$w_i(k)$	Water inflow to the reservoir i , hour k [he]
$u_{is}(k)$	Water discharge from plant i , hour k [he]
$sp_i(k)$	Water spillage from plant i , hour k [he]
τ_{ij}	Water delay time from reservoir i to next downstream reservoir j
H_i	Number of the whole hours from reservoir i to the next downstream reservoir j
M_i	Number of minutes in addition to whole hours from reservoir i to next downstream reservoir j
T	Last time step in the evaluation period
D. Variables	
$\Delta P_{is}(k)$	Power saved in hydro plant i , segment j , hour k [MW]
$\Delta u_{is}(k)$	Increase in discharge for hydro plant i , segment j , hour k [he]
$P_w(k)$	Wind power production, hour k [MW]
$P_{12}(k)$	Power transmission, hour k [MW]
$P_s(k)$	Power production in slack source, hour k [MW]
z^s	Total power production cost in slack source [SEK]
z^e	Value of water saved in hydro reservoirs at the end of the studied period [SEK]
z	Objective function [SEK]

II. BACKGROUND

IN the recent years the increase in electricity demand and environmental concern are encouraging the growth of power production from renewable sources. One of the most efficient alternatives is wind power. However considerable wind resources are often located in remote areas with low population density, where transmission system is weak. In

case integration of large-scale generation it may become subject to congestion problems. New rules for connection of large wind farms (WF) to the transmission system require WF be able to decrease their production in case of congestions in the system [1], [2], [3], [4]. With this requirement the necessity arises for careful evaluation of the size of new-planned WF. First costs for possible wind energy curtailments should be compared to costs for necessary grid reinforcement [5]. Furthermore, the alternatives for storage of excess wind energy might be considered. For large WF battery storage is extremely expensive and therefore conventional power sources can be employed for wind energy storage. Hydropower plants (HPP) situated on the same side of the bottleneck are more suitable for this purpose as their power production may be regulated rather fast.

In this paper the possibility to use HPP for storage of excess wind energy during congestion situations in the transmission system is evaluated. The suggested method allows us to analyse previous years of operation of the power system (e.g. dry, wet and normal year) and conclude what physical possibilities for wind energy storage existed.

The results of such analysis are helpful in the decision-making about the size of the WF in areas with congestion problems. The method can be directly applied for utilities with hydropower production considering future investments in wind power.

If WF and HPP are owned by different utilities, the trade-off between wind energy curtailment and storage in hydro reservoirs will be made within a framework of liberalised electricity market. However, even in this case, the suggested method can be used as the estimate of storage possibilities.

It is possible to include wind power in HPP production planning as suggested in [6]. However in [6] it is difficult to separate effect of wind power and effect of congestions in the transmission system on HPP production.

The outline of the paper is as follows. Section III provides an overview of the Swedish power system as an example of system with congestion problems and substantial storage capabilities. Section IV discusses wind power in Sweden. In Sections V, VI and VII the evaluation method is presented in details. The suggested method is then applied to one of the existing Swedish hydro reservoir systems, Section VIII, and the results of the evaluation are discussed in Section IX.

III. SWEDISH POWER SYSTEM

The Swedish transmission system was built up to use hydropower as efficiently as possible following the expected increase in electricity consumption. The installed capacity is about 32 000 MW of which 51.2 % is hydropower, 29.7 % is nuclear power, 18.1 % thermal power. Installed wind power corresponds to about 1.1 % of the total installed capacity.

The major hydro power stations are situated on the long rivers in the northern part of Sweden and there are large reservoirs for seasonal and annual storage with total capacity of 33,6 TWh. The reservoirs and hydropower stations are coupled to each other and form the complex river system with many constraints.

Eight long 400 kV transmission lines connect the northern part of the transmission system with central and southern parts, where the main load is concentrated. During cold winter days when the system is highly loaded or during the spring flood, a lot of power is transferred from the north, and the power transmission is almost at the limit. The bottlenecks within Swedish power systems and with neighbouring countries are shown in Fig. 1.

IV. WIND POWER IN SWEDEN

The development of wind power in Sweden is much slower compared to e.g. Denmark, Germany and Spain. The installed capacity of wind power amounts to 358 MW (March 2003). The WFs and WTGs are mostly spread along the southern coast, on and near shore of the islands of Gotland and Öland. One of the causes of such slow development is that about 50% of power is already produced by a renewable source – hydropower. Furthermore in case of large-scale integration the existing transmission system may require reinforcement as it contains several bottlenecks already now, Fig.1.

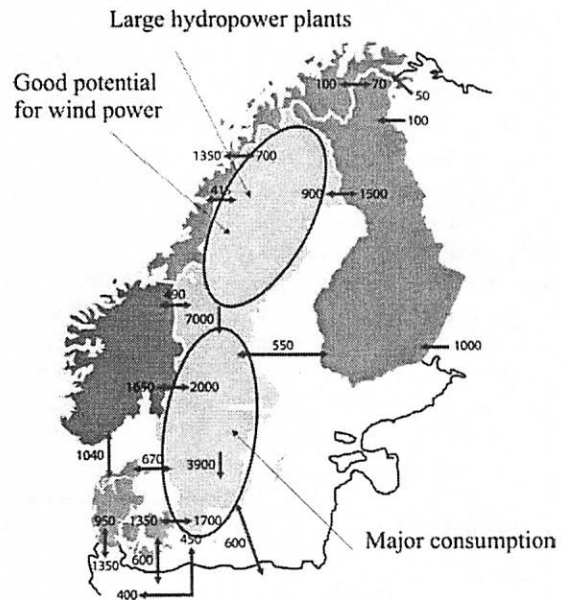


Fig. 1. The bottlenecks within Swedish power systems and with neighboring countries.

The Swedish government proposed a bill on planning objectives for wind power. According to the bill 10 TWh of wind power production per year should be achieved up to 2015. The bill was approved in 2002 and since then several studies were conducted in order to draw up prerequisites for integration of wind power in Sweden. In 2002 the Swedish government commissioned TSO Svenska Kraftnät to draw up overall prerequisites for integration of large-scale wind power (10 TWh) in mountainous and offshore areas. In the resulting report the case with 4000 MW (utilisation time 2500 hours) of wind power penetration in northern Sweden was considered [7]. According to the report, 5 new 400 kV-transmission lines with the total cost of 20 000 MSEK would be necessary to

make electricity transmission available during 100% of the year.

It is obvious that construction of new transmission lines is an expensive option. One alternative for large-scale wind power integration in congested areas (e.g. northern Sweden) is studied in [5], where wind energy curtailment was estimated and weighted against the costs for grid reinforcement. In the following the excess wind energy storage in hydro reservoirs is considered to decrease wind energy curtailment during congestions in the transmission system.

V. WIND ENERGY STORAGE IN HYDRO RESERVOIRS

Since the demand of electricity does not match the natural flow in the rivers there are reservoirs located upstream of the most hydropower plants. Large reservoirs are capable to store water from the spring flood to the winter when the demand is high. Smaller reservoirs are suited to match the electric demand variations on weekly or daily basis. These capabilities can be used to store wind energy during the congestion problems.

When congestion occur hydro power production may be decreased allowing WF still produce power without curtailment. Water that is thus saved in hydro reservoirs can be considered as stored wind energy. The storage capabilities of HPP are consequently defined not only by size of hydro reservoir but also by scheduled hydropower production.

When evaluating the possibility to use hydropower for wind energy storage, the main complication is that hydropower production is planned differently by different production utilities. There is large variation in modelling regarding a level of details, representation of uncertainties etc. The planning strategies are confidential. Furthermore the strategies are not always optimal, because of unexpected events, e.g. generator outages or participation in the regulating market etc. Therefore, to make more realistic estimation of hydropower storage capabilities, one may use known production of HPP for previous years of operation and analyse physical capabilities of hydro reservoirs at different levels of wind power penetration.

VI. EVALUATION METHOD

In the model used for the evaluation, it is assumed that hydropower and wind power are situated in the same area. Main load and thermal power is concentrated in the other area. Transmission line with limited transmission capacity is connecting these areas (see also Fig. 1). It is assumed that all generated wind power can potentially be consumed.

Fig. 2 shows the flow chart of the evaluation method. Potential wind power is represented using wind speed measurements from the studied year; the power is calculated from the wind speeds, using wind turbine power curve, and scaled to represent different penetration levels (box A). Data regarding power consumption during the same year is used (box B). Real hydropower production during the studied year is considered as hydropower production plan (box D). If power transmission (box E) is not congested (box G, NO)

hydropower is produced according to production plan (as in box D). When the congestion occurs (box G, YES) the hydro production is reduced, i.e. wind energy is stored in hydro reservoir in order to minimise wind energy curtailment (box F). Hydropower production plan is modified in order to use saved water optimally during the subsequent hours of operation (box F).

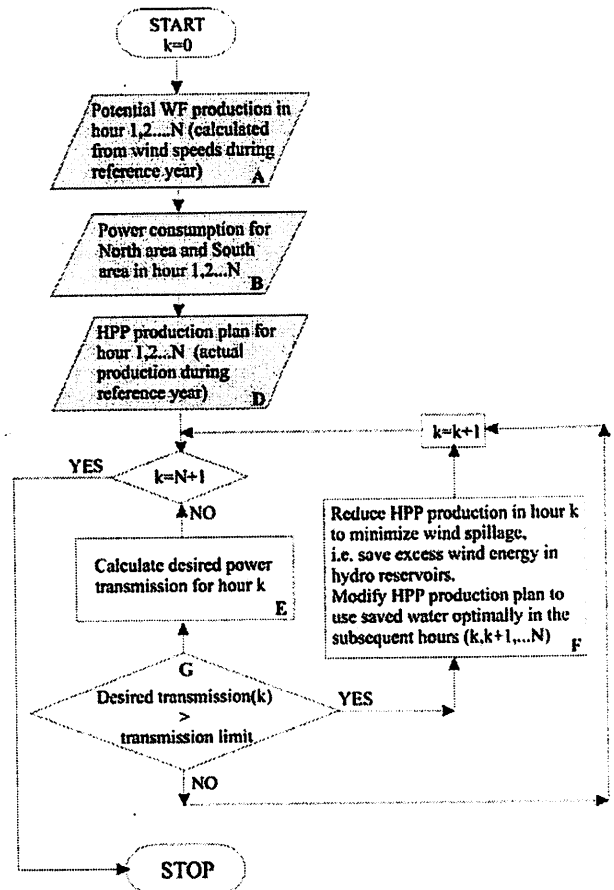


Fig. 2. The flow chart of the evaluation method.

The optimisation model is defined in order to reschedule HPPs to allow storage of excess wind energy in hydro reservoirs during congestions and utilisation of saved water in the subsequent hours. In this paper the benefit for the power system as a whole is evaluated, i.e. benefit from producing more power with wind and hydro instead of more expensive power sources. However if necessary the optimisation model can be slightly adjusted to evaluate benefits for the particular actors, e.g. HPP owners.

VII. MATHEMATICAL FORMULATION

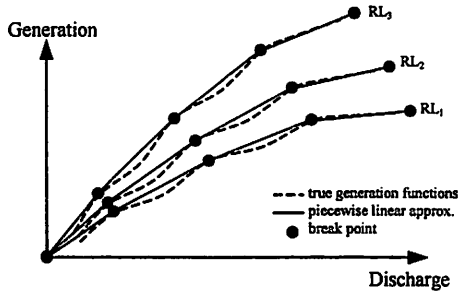
In this section the mathematical formulation of the optimisation problem is presented in details.

A. Model for hydropower generation as a function of discharge

The generation of each unit in HPP is non-linear function of upstream and downstream reservoir levels, efficiency of

turbine/generator set and water discharge. Generation functions for all units form HPP's production curve, which is non-concave. For this studies discharge-generation relationship was approximated by piecewise linear function. Local best efficiency points of the true generation function and the point of maximum discharge are chosen as breakpoints, Fig. 3. The slope of each linear segment is called production equivalent, μ_{is} . With piecewise linear approximation of generation function linear programming methods can be used to solve the optimisation problem.

Fig. 3. Hydropower generation as function of discharge. Generation functions are shown for three different reservoir levels (RL), $RL_1 < RL_2 < RL_3$.



The changes in generation function with change of upstream and downstream reservoir level are not considered in these studies. However a possible impact of wind energy storage on efficiency of HPPs is discussed in the Appendix.

B. Objective function

The objective of this evaluation is to minimize the costs for power production under consideration of the future water value. The water value indicates the benefit of using the water in the future instead of using it during the studied period.

In this paper power sources other than wind and hydro have been combined to a slack source with maximum capacity \bar{P}_s . The cost for power production can thus be expressed as

$$z^f = c^f \sum_{k \in K} P_s(k) \quad (1)$$

The value of saved water is defined as:

$$z^e = c^e \sum_{i \in I} x_i(T+1) \sum_{i \in \Gamma_i} \gamma_i \quad (2)$$

As our study concern the previous years of operation expected price c^e , i.e. the price at the end of studied period is assumed known. The average production equivalent γ_i is assumed for water value calculation.

$$\gamma_i = \frac{\sum_{s \in S} \mu_{is} \bar{u}_{is}}{\sum_{s \in S} \bar{u}_{is}}, \quad \forall i \in I \quad (3)$$

The objective function can now be formulated as follows:

$$z = \min(z^f - z^e) \quad (4)$$

C. Hydrological constraints

The hydrological constraints describe couplings between adjacent HPPs. In hydropower production planning the hydrological constraints are formulated as follows:

$$x_i(k+1) = x_i(k) - \sum_{s \in S_i} u_{is}(k) - sp_i(k) + w_i(k) + \sum_{j \in \Omega_i} \left[\sum_{s \in S_j} u_{js}(k - \tau_{ji}) + sp_j(k - \tau_{ji}) \right], \quad \forall i \in I, \forall k \in K \quad (5)$$

The reservoir content of the particular HPP is affected by spillage and discharge in HPPs directly upstream.

The delay time τ_{ij} between HPP j and HPP i directly downstream is assumed to be defined in H_j hours and M_j minutes. The discharge considering the delay time can then be expressed as

$$u_{js}(k - \tau_{ji}) = \frac{M_j}{60} u_{js}(k - H_j - 1) + \frac{60 - M_j}{60} u_{js}(k - H_j) \quad (6)$$

$$\forall j \in J, \forall s \in S_j, \forall k \in K$$

Analogously a spillage $sp_j(k - \tau_{ji})$ can be determined [8].

For our evaluation method the hydrological constraints (5) need to be adjusted as follows:

$$x_i(k+1) = x_i(k) - \sum_{s \in S_i} u_{is}(k) - sp_i(k) + w_i(k) + \sum_{j \in \Omega_i} \left[\sum_{s \in S_j} u_{js}(k - \tau_{ji}) + sp_j(k - \tau_{ji}) \right] + \sum_{s \in S_i} \left(\frac{\Delta P_{is}(k)}{\mu_{is}} - \Delta u_{is}(k) \right) + \sum_{j \in \Omega_i, s \in S_j} \left(-\frac{\Delta P_{js}(k - \tau_{ji})}{\mu_{js}} + \Delta u_{js}(k - \tau_{ji}) \right), \quad \forall i \in I, \forall k \in K \quad (7)$$

The last terms include the effect on hydro reservoir content from storage wind energy in hydro reservoir and from the disposal of stored water, in the local station and the stations directly upstream (references to more detailed representation of hydrological constraints are given in Appendix). As it was defined above, storage of wind energy in hydro reservoirs means decrease of HPPs production, $\Delta P_i(k)$ in MW. However reservoir content in hydrological constraint is expressed in h_e , this means that we have to convert $\Delta P_i(k)$ to h_e using HPP's production function, Fig. 3. This converted value should not exceed the planned discharge $u_{is}(k)$, because it is not possible to pump water back:

$$0 \leq \frac{\Delta P_{is}(k)}{\mu_{is}} \leq u_{is}(k), \quad \forall i \in I, \forall s \in S, \forall k \in K_c \quad (8)$$

Initial reservoir content is set as:

$$x_i(0) = x_i^0 \quad (9)$$

Hydro reservoir content and water discharge should always be within the limits set by technical and environmental constraints, i.e.:

$$0 \leq x_i(k) \leq \bar{x}_i, \quad \forall i \in I, \forall k \in K \quad (10)$$

$$0 \leq u_{is}(k) + \Delta u_{is}(k) \leq \bar{u}_{is}, \quad \forall i \in I, \forall s \in S, \forall k \in K \quad (11)$$

Additional water spillage due to wind energy storage in hydro reservoirs is not allowed in the evaluation model.

D. Energy storage and load balance constraints

In the evaluation method it is assumed that planned hydropower production should only be reduced during congestion situations in order to allow wind power production without curtailments. Since the previous years of operation are

studied the need for wind energy storage during congestion situations for the considered two-area model, Fig. 1, can be expressed as follows:

$$\sum_{i \in I} \sum_{s \in S_i} \Delta P_{is}(k) \leq \left(\sum_{i \in I} \sum_{s \in S_i} \mu_{is} u_{is}(k) + \bar{P}_{wind}(k) - D_1(k) \right) - \bar{P}_{12}, \quad (12)$$

$$\forall k \in K_c$$

Term $\sum_{i \in I} \sum_{s \in S_i} \mu_{is} u_{is}(k)$ corresponds to power production in HPP

i , hour k . Constraint (12) states that needs for wind energy storage is less or equal to potential wind energy curtailment during congestion situations.

If transmission is not congested no wind energy is saved in hydro reservoirs:

$$\sum_{i \in I} \sum_{s \in S_i} \Delta P_{is}(k) = 0, \quad \forall k \in K_{nc} \quad (13)$$

Otherwise if transmission is congested there should be no additional hydropower production, i.e.:

$$\sum_{i \in I} \sum_{s \in S_i} \Delta u_{is}(k) = 0, \quad \forall k \in K_c \quad (14)$$

The optimisation problem will be also subjected to power balance constraints:

$$D_1(k) = \sum_{i \in I} \sum_{s \in S_i} \left[\mu_{is} (u_{is}(k) + \Delta u_{is}(k)) - \Delta P_{is}(k) \right] + P_w(k) - P_{12}(k) \quad (15)$$

$$D_2(k) \leq P_s(k) + P_{12}(k), \quad \forall k \in K$$

Term $\sum_{i \in I} \sum_{s \in S_i} \left[\mu_{is} (u_{is}(k) + \Delta u_{is}(k)) - \Delta P_{is}(k) \right]$ corresponds to

adjusted production in HPP i . Less or equal sign is used in power balance equation for second area to represent the assumption that all produced wind power can be consumed on the other side of the bottleneck.

In addition power transmission should always be within limits

$$P_{12}(k) \leq \bar{P}_{12}(k), \quad \forall k \in K \quad (16)$$

Depending on particular case study transmission limit can be assumed constant or varying in time.

Capacity of wind power sources and slack source are limited by following constraints

$$0 \leq P_w(k) \leq \bar{P}_w(k), \quad 0 \leq P_s(k) \leq \bar{P}_s \quad (17)$$

The difference between $P_w(k)$ and $\bar{P}_w(k)$ correspond to amount of wind energy curtailment during hour k .

Additional discharge during should be less or equal to amount of saved water due to wind energy storage.

$$\sum_{k \in K} \sum_{s \in S_i} \Delta u_{is}(k) \leq \sum_{k \in K} \sum_{s \in S_i} \frac{\Delta P_{is}(k)}{\mu_{is}}, \quad \forall i \in I, \forall k \in K \quad (18)$$

VIII. CASE STUDY

The developed evaluation model is now applied to a study case. For this study Swedish power system is divided into two parts as in Fig. 1.

The aim of the case study is to evaluate how much wind power can be integrated in the northern part of Sweden before transmission system reinforcement becomes more economic option than wind energy curtailment. Evaluation of wind energy curtailments was presented in [5]. However possibility to store excess wind energy in hydro reservoirs was not

considered in that study.

As it was mentioned above more than 50% of power in Sweden is generated by HPPs. Most of these HPPs are situated in northern Sweden and have considerable storage capability. However operation data from HPPs on one river only were available for this study. Therefore it is assumed that only one hydro reservoir system, Fig. 4, can be employed for wind energy storage. Installed capacity of this system is 567 MW. The operation of other HPPs is left unchanged. Operation data from 2001 are used for the case study.

To model wind power production the wind speed data from Sourva (northern Sweden) from 2001 were converted to power using a power curve and scaled to represent different levels of wind power penetration.

Load measurements from both areas during 2001 are available for this case study.

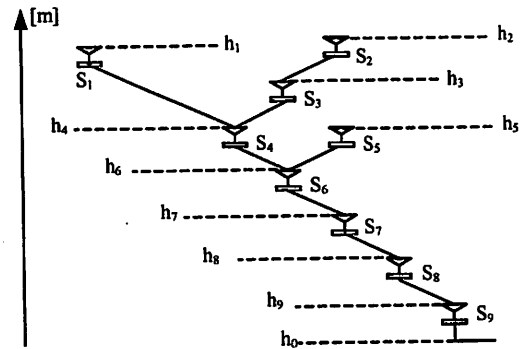


Fig. 4. Hydro reservoir system that is used for wind energy storage in the case study.

New transmission (with wind power) between the areas is calculated in advance to define set of hours when transmission is congested K_c and the set of hours when transmission is not congested $K_{nc}=K-K_c$. Transmission limit is assumed constant in this studies and equal 7000 MW, which corresponds to transmission capability of eight transmission lines connecting northern Sweden with central and southern part.

A. Case study with 1000 MW wind power in Northern Sweden

Fig. 5. presents actual power transmission in 2001 and desired power transmission if 1000 MW of wind power would be installed in northern Sweden in 2001. For illustrative purposes transmission duration curves are shown, i.e. number of hours when transmission was acceding a certain level.

From Fig. 5 follows that with 1000 MW wind power transmission limit was acceded during 94 hours of the year and 28 719 MWh of wind energy would be subjected to curtailment. Optimisation problem described by equations (1)-(4) and (6)-(18) is solved to see how wind energy storage in hydro reservoirs affects these figures.

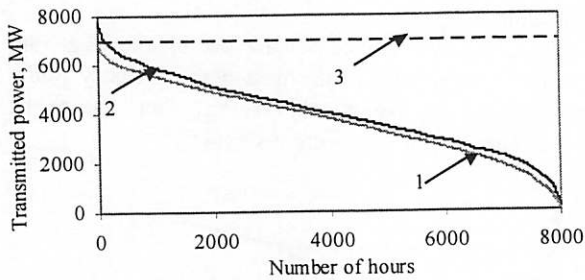


Fig. 5. Duration curve of power transmission from northern Sweden to central and southern part in Jan.-Nov. 2001 (curve 1), desired transmission duration curve with 1000 MW wind power (curve 2), transmission limit (curve 3).

With one hydro reservoir system acting as storage for excess wind energy during congestion problems wind energy curtailment is reduced to 5 926 MWh.

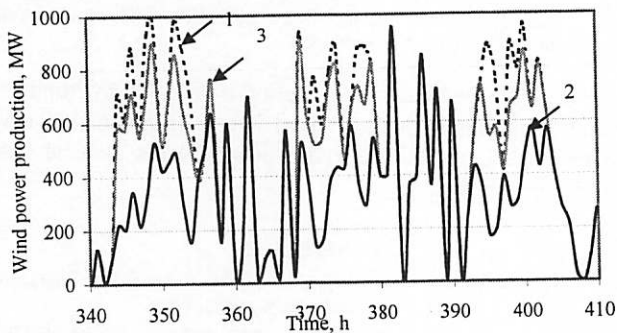


Fig. 6. Desired wind power production (curve 1), wind power production with excess wind energy curtailment during congestion situations (curve 2), wind power production with excess wind energy storage in hydro reservoirs (curve 3).

For illustrative purposes wind power production is shown Fig. 6 for several hours in the studied period. Fig. 7 shows how power transmission is effected in the same period.

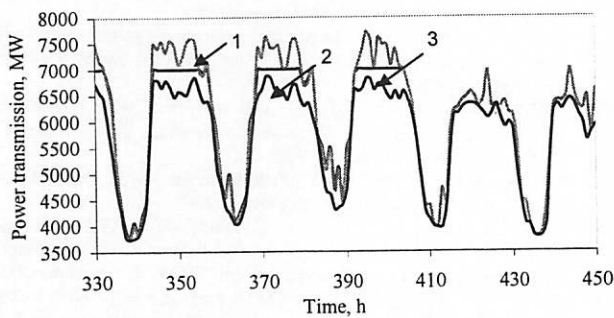


Fig. 7. Desired power transmission (curve 1), transmission with wind energy curtailment during congestion situations (curve 2), wind power production with excess wind energy storage in hydro reservoirs.

Due to the fact that only one river system with total installed capacity of 567 MW is assumed to be employed for wind energy storage it is really difficult to see from Fig. 7 how the disposal of saved water effects the transmission. Total power transmission during the studied period is 31.88 TWh for the case when wind power is curtailed during the congestion situations and 31.92 TWh for the case when excess

wind power is saved in hydro reservoirs and disposed later on.

The effect of wind energy storage on hydro reservoir level for large reservoir S_3 and small reservoir S_7 (see Fig. 1) is shown in Fig. 8 and Fig. 9 respectively.

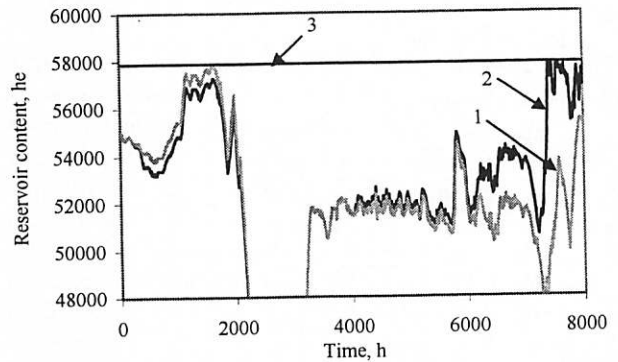


Fig. 8. Content of reservoir S_3 : actual values for Jan. - Nov. 2001 (curve 1), with wind power storage in hydro reservoirs (curve 2), maximum reservoir content (curve 3)

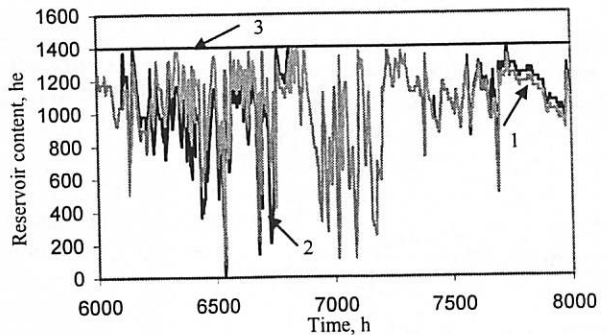


Fig. 9. Content of reservoir S_7 : actual values for Jan. - Nov. 2001 (curve 1), with wind power storage in hydro reservoirs (curve 2), maximum reservoir content (curve 3)

The optimisation problem is solved using linear programming methods, i.e. all equations (1)-(4) and (6)-(18) are solved simultaneously. Therefore the model tends to reduce reservoir content in the beginning, Fig. 8 and Fig. 9, to have more margin for wind energy storage when necessary. However condition (18) does not allow total additional discharge to be greater than total stored power, this keeps hydropower production close to production plan.

IX. DISCUSSION

This paper has presented a method for evaluation of wind energy storage in hydro reservoirs in areas with limited transmission capacity. The evaluation method was tested with the case study. The results have proven that using storage capabilities of hydro reservoirs more wind power can be installed in areas with limited transmission capacity and curtailment of wind energy is thus minimised. Furthermore, the existing transmission lines are better utilised, more energy can be transmitted during a year.

The method can be applied by hydropower utilities, considering investments in wind power, in decision-making about the size of WF.

If wind farm and hydropower are owned by different utilities, the trade-off between wind energy curtailment and storage in hydro reservoirs will be made within a framework of liberalised electricity market. Note that in the following it is assumed that wind power is sold in the spot market along with conventional power sources.

If the bottleneck is predicted by TSO prior the price setting in the spot market, the market may split into separate bid areas on each side of the bottleneck in order to maintain power transfer limit (different price areas exist e.g. in Norway and Denmark). Thus a higher price is established in the receiving end area than in sending end area; power is then bought from the sending end area until the transmission capacity reaches the limit [9], [10]. Wind power has zero marginal cost and therefore it is assumed that it is always sold on the market. If prices in the sending end area are low and hydro power plants have storage capability it is better to store water until period when congestion is relaxed and spot prices are higher. Therefore hydropower plants will naturally respond to a bottleneck by production reduction.

If the bottleneck occurs during the operation hour because of unexpected wind power production increase the regulation down from hydropower will be bought by TSO on the regulating market this is called counter trading. Alternatively the excess wind energy may be curtailed.

The suggested evaluation method can also be employed by TSO or energy authorities to draw overall prerequisites for integration of large-scale wind power in areas with limited transmission capacity.

X. APPENDIX

The changes in generation function with change of upstream and downstream reservoir level are not considered in these studies. However it should be pointed out that wind energy storage in hydro reservoirs would generally result in increase of hydro reservoir levels and thus may lead to higher production equivalents in subsequent hours. The method for modelling this effect in hydropower production planning is suggested in [10] and [11].

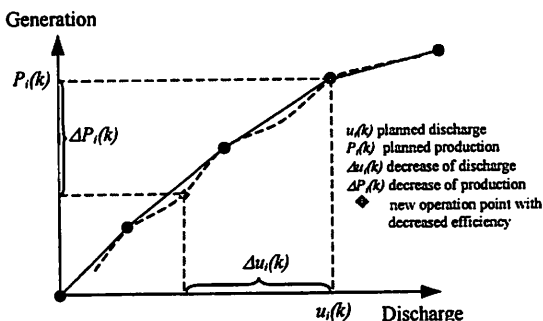


Fig. 10. Example of efficiency reduction due to wind energy storage in hydro reservoirs.

Hydropower production reduction to store wind energy in hydro reservoirs on the other hand may occasionally result in decrease of production efficiency during the actual hour, as

the units will be forced to operate further from the best efficiency points, Fig. 10.

This efficiency reduction can be avoided by allowing wind power storage only down to the next best efficiency point, Fig. 11. The rest of excess wind energy then has to be curtailed or saved in another hydro reservoir.

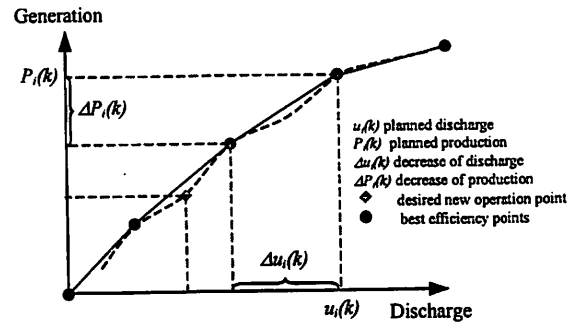


Fig. 11. Example of maintaining high efficiency in HPPs while saving excess wind energy during congestion problems.

This, more detailed, representation is useful in hydropower production planning stage. Mixed integer programming may be employed to schedule hydro power plants at local best efficiency points [11].

XI. REFERENCES

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XII. BIOGRAPHIES

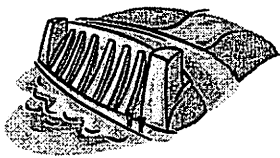


Julija Matevosyan (Sveca) was born in Riga, Latvia in 1978. She received her B.Sc. degree in Electrical Engineering from Riga Technical University, Latvia, in 1999, M.Sc. degree in Electrical Engineering from the Royal Institute of Technology, Stockholm, Sweden in 2001. She is currently working on a PhD on large-scale integration of wind power in areas with limited transmission capability at the Royal Institute of Technology. E-mail: julija@ekc.kth.se

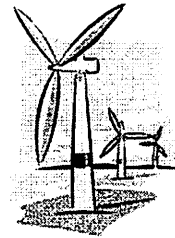


Lennart Söder was born in Solna, Sweden in 1956. He received his M.Sc. and Ph.D. degrees in Electrical Engineering from the Royal Institute of Technology, Stockholm, Sweden in 1982 and 1988 respectively. He is currently a professor in Electric Power Systems at the Royal Institute of Technology. He also works with projects concerning deregulated electricity markets, distribution systems and integration of wind power. E-mail: lennart.soder@ekc.kth.se

Management of Hydropower and Wind Power on the Daily Electricity Market



Magnus Olsson
magnus.olsson@ekc.kth.se



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Outline

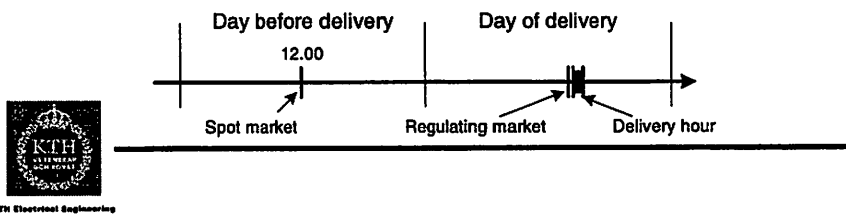
1. Research project
 - i. Nordic power market
 - ii. Hydropower and wind power
 - iii. Problem description
2. Papers
 - i. "Hydroplanning model including trade-off..."
 - ii. "Generating regulating power price scenarios"
3. Future work



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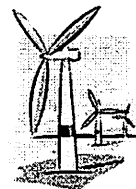
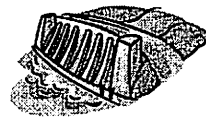
Power market

- Nordic spot market (Nord Pool's Elspot)
 - Hourly day-ahead spot market
 - Bids placed until noon the day before delivery
- Elbas (EL-EX)
 - Adjustment market
- Swedish regulating market
 - Balance market where SvK (TSO) buys regulating power
 - Bids placed until 30 minutes before the actual hour
 - Different prices for upward and downward regulation



Hydro and wind

- Hydropower:
 - Large amounts of hydropower in Sweden (66 TWh of 143 TWh in 2002)
 - Flexible power source
- Windpower:
 - Today to small amounts to have any impact on the power system
 - Levels up to 10 TWh/year has been discussed
 - Larger amounts will affect prices and volumes on the regulating market
 - Increased need for regulating power



The problem

- Trading on the spot market requires 36 h forecasts
⇒ problems for wind power producers
- Two ways of handle the problem:
 - Sell power on the spot market according to forecasts
 - Coordinate hydropower plants with wind power plants
- Results in a need for planning tools considering the increased planning uncertainty



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Objective

”Hydropower planning including trade-off between energy and reserve markets”

Create a hydropower planning model considering sales on the energy market (= Nordic spot market) and the reserve market (= Swedish regulating market)



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Planning model

- Short-term hydropower planning model covering the next 24 hours
- Trade-off between:
 - selling on spot market
 - selling on regulating market
 - saving the water for future power production
- Formulated as a stochastic programming problem



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Objective

”Generating regulating power price scenarios”

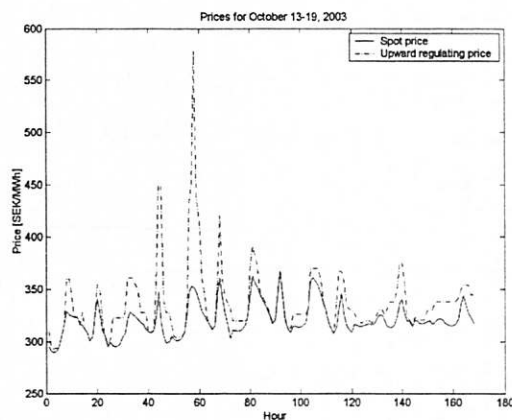
Create a model for the regulating market prices to use when constructing scenario trees, which will be used in optimization models to generate optimal bids to the regulating market.



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Spot price

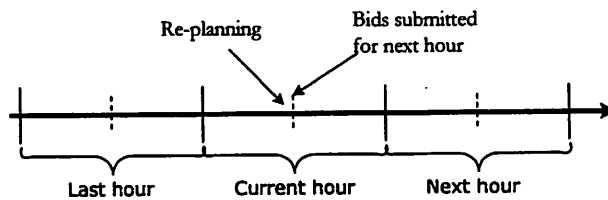
- Spot prices known when planning takes place.
- Strong correlations between spot market price and regulating market prices.



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Re-planning

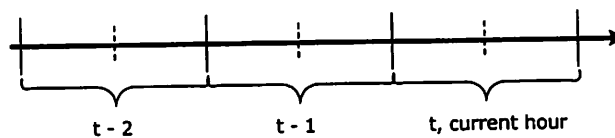
- Re-planning before each hour according to new information.



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Time lag

- How long time it takes before the prices and volumes becomes public



What past prices are known when deciding the bids for the next hour?



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3. Future work



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Future work

- Hydropower planning model for creating optimal bids to the regulating market, including a scenario tree.
- How will the stochastic behaviour of the regulating market be affected by increased amounts of wind power in the system?
- Consider the Elbas power market.



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Summary of IEA R&D Wind – 41st Topical Expert Meeting on

Integration of Wind and Hydropower Systems

November, 2003, Portland, USA
Deborah Linke, Tom Acker and Sven-Erik Thor

Background

Wind power is an intermittent, variable power output technology. Because of these characteristics, wind power is typically not controlled, or dispatched, by utilities. This operational mode imposes unique challenges on integrated utility grid operations. When low amounts of wind are added to an interconnected grid system, changes to grid operations are minor or negligible. However, as wind penetration increases, operations of other generators may require modification, resulting in increased costs allocated to the added wind generation. Although these additional costs do not occur only with wind generation additions, the nature of these additional requirements associated with wind is of considerable interest. The imposed additional system costs are a function of grid characteristics and increasing wind penetration, and are not well characterized at this time. These additional system costs are becoming a prime concern, in some countries, because the lifecycle costs of wind generation equipment have decreased to levels competitive with conventional fossil-based generation, and are expected to create strong interest in wind power capacity additions. In other countries wind is considered as a benefit, not associated with extra system costs.

Participants

The meeting gathered 28 persons from 4 different countries, Canada, Norway, Sweden and USA. Six of the participants came from outside of the US. Participants came mainly from utilities in USA and had a hydropower background.

Presentations

Brian Parsons-NREL

Old issues were based on technology like turbines that are efficient with rough services, cracking on turbines. Pricing has come down for wind. Coupled with incentive tax credits pricing coming in under 3 cents per kwh for good sites with large wind farms.

The goal of the meeting is to:

- Identify technical, institutional, economic and political issues associated with integrating wind and hydro
- Inventory lessons learned from prior work around the world.
- Consideration will also be given to establishing a formal technical IEA Wind-Hydro integration activity.

Showed graph of Lake Benton and Storm Lake production sites that are separated by 150 miles. The correlated patterns show a delay between production fluctuations. Views regulation as in the seconds to minutes time frame, load following as the minutes to hours time frame. Believes the long-term impacts are the big issues and include in the forecasting

of production, required reserves, dealing with system contingencies and the provision of ancillary services. Several studies have been done which suggest that at low penetration rates, the costs seem to be relatively low.

Study (Penetration)	Time-Scale	Cost \$/MWh of wind delivered
Hirst, PJM (0.06-0.12%)	Regulation, Imbalance	.05-.30
Electrotek Xcel (3.5%)	Regulation, Load following, Reserves, Unit Commitment	2
Pacific Corp(20%)	Imbalance, Resources	5.50
Hirst BPA (6%)	Regulation, LF, Imbalance, Day Ahead	1.37-2.17

Transmission continues to be a problem since there is no new transmission being built. Low capacity factor of wind is not conducive to building new lines.

Views hydro as variable-seasonal and annual flow fluctuation. Constrained: Multiple demands dictate flows, increasing environmental pressure. Quick response. Sees hydro as short-term wind buffer, wind allows longer-term water time shifting. Believes there could be more flexibility in operations of both power sources, better utilization of transmission. Opportunities may exist to develop green markets and use federal projects for additional public benefits.

Frans Koch-IEA Hydropower Implementing Agreement Secretary

Role of Hydropower in Renewables Mix: Wind generation is 28.9 TWh annually world wide. No good estimate of total hydropower storage globally. Reservoir capacity can vary widely from country to country. During dry years hydro intensive countries are not usually able to meet demand. Not every country has hydropower capability. Pumped storage may be a good mix for integration with intermittent generation. US and Japan have 19 GWh installed capacity each. Pumped storage costs \$2000-\$4000 per MW installed capacity.

Economic framework: Many countries have liberalized electricity markets. Market rules for ancillary services vary widely. Coal and natural gas are the lowest cost technologies in North America.

Public Acceptance: Public acceptance is a large issue for hydro. Wind power has a very positive public image. Could be an opportunity for an opportunity for a public acceptance coalition. BPA has integrated wind/hydro and has run into issues with environmental groups when the attempt melding wind/hydro as a clean resource.

Cheap oil and gas could be depleted in 20 to 40 years in BRIC countries-Brazil, Russia, India, China). Only feasible options for the future power sector in terms of cost and scale are clean coal, nuclear, and wind/hydro. Transportation sector might become an important end user of electricity that could increase demand for electricity by 50 to 100%. Clean coal and nuclear are the ceiling for price 8-10 cents/kWh. Public issues include energy security and environmental. Scale for wind is an important consideration. Like hydro, wind may run out of good sites. Economic incentives drive the installation of wind.

Individual reservoir hydro facilities have limits on upper and lower levels of the reservoir. Transmission system is often limited. Hydro plants typically have capacity factor of 70%, which leaves capacity available without water.

Parsons: Getting higher capacity factors 20-30% from taller towers. Mainzer: Constraints to market are usually transmission capacity. Pacific Corps has challenged concept that intermittent wind energy has a low value in de-regulated electricity market. Have been selling wind in the hourly market. Requires better forecasting so they hired Three Tier forecasting which improved forecasting to 90-95% accuracy. Nordic markets pay market rates for imbalances. Daily market means you cannot hedge against the market. NW does not have a bid-in market. Market in West far away from PJM market rules which do not penalize intermittent generators.

Hydropower R&D Program-Jim Ahlgrimm, Technology Manager, Wind and Hydropower Technologies Program.

\$5 million program expenditures. Two goals. Technology Viability Goal-By 2010, new technology that will enable 10% growth in hydropower generation at existing plants with enhanced environmental performance. Items include develop new hydropower turbines for fish friendly turbine, water use & operations optimization, and improved mitigation practices. Supporting research includes Biological Design criteria, computer and physical modeling, instrumentation and controls and environmental analysis. Technology Application: Complete program activities to enable undeveloped hydropower capacity to be harnessed in the US without construction of new dams.

Michael Sale-DOE Environmental Sciences Division, Oak Ridge National Lab

Large projects being certified in as environmentally preferable. Recognizing that big or small is not the only delineation. Skagit River Project just got certified as a green acceptable project. Wind hydro integration depends on operational flexibility. Integration goal: maximize system dependability. Shift hydro generation to periods of low wind availability.

Potential benefits- New product for hydro firming/shaping. Help marketability of wind, wind energy complement hydro in low water years. Water savings, improved renewables package. Federal projects are 10 times bigger than non-federal, although capacity is about the same.

Project purposes and demands are the drivers on flexibility. Multipurpose objectives, power sales agreements, water rights, water deliveries, seasonal flood control rules (particularly at large federal projects). Don't own the water that goes through the dams and hydropower plants. Hydropower operation is a matter of balance among project storage and volume, rule curves, seasonality, and active storage.

Hydrology is basis for operations. Annual hydrograph type, river basin type, hydrologic variability, upstream reservoirs, and changing values for environmental protection all impact hydrology available for integration. Environmental requirements affecting operations include: In-stream flow requirements, recreational flows, reservoir-based recreation for pool elevation constraints, and stakeholder relations.

Good combinations for wind hydro integration: Reservoirs with large storage, large active power pools, multiple dams with re-regulation capability, flexible water/power contracts. Small run of river plants can help with instantaneous, hour to hour fluctuate.

Bad combinations: Over-allocated projects, run of river projects, projects subject to ESA or other institutional problems.

Technology solutions-re-regulating weirs, better science for in-stream flow requirements.

Parsons: What role will pumped-storage have? Capacity is expensive. Pumped-storage price differential needs to be \$40-55 between heavy load and light load hours on a sustained basis. Linke pointed out that Mt. Elbert has become a valuable resource for Loveland Area Projects.

Brian Parsons National Renewable Energy Laboratory-Targeting large federal projects. Western Area Power Administration Cooperative Analysis. Goal is to highlight opportunity and motivate use of the system. Arizona Power Authority Colorado River Scoping & Missouri River System Potential: tie to Wind on the Wires effort.

BPA Cooperative Analysis. Much internal activity already underway plus Eric Hirst study. \$40 million wind program. Hydro gets \$10 million.

Tom Acker Associate Professor, Mechanical Engineering NAU on sabbatical with NREL
Full time through April, then part time after that.

Approach to study-characterize problem, study of technical feasibility, what does it take to integrate hydro with wind, how to model, which organizations need to be involved. Follow this work with economic studies and benefits assessment including how hydro benefits. Use case studies and develop education and outreach.

Problem characterization-Literature review of lessons learned, characterize technical challenges of integrating hydropower and wind from standpoint of river operations, generation system control and operational issues, devise plan for study of these challenges and collaborate with appropriate institutions.

Technical Feasibility- Best wind areas upper mid West where there is little load. Wind hydro resource availability, hydro system operation and modeling, transmission availability and access, economic and optimization studies. Also need to understand where loads are available.

BPA-NW winds come from Arctic, cold, still air masses decrease wind resource while the load spikes at the same time. Ideal places are where hydro is down while wind is at peak. Wind and loads are inversely related in NW.

Economic studies-order of magnitude how much can be integrated, preliminary studies on Columbia & Snake, Colorado, and Missouri Basin. Integration is a larger issue than just wind/hydro, really is a broad issue. Integration with the grid is the larger issue.

Deborah Linke-US Bureau of Reclamation

Reclamation hydropower plants built as part of water development projects and water deliveries come first. Hydropower generation is a result of water deliveries. Primary purpose of Reclamation generation is power for project purposes. Power surplus to those needs is available to Power Marketing Administrations (Bonneville & Western) for sale at cost based rates

Reclamation's water is marketed via long-term contracts for irrigation and municipal purposes. Water deliveries are subject to project specific authorizing law and environmental requirements. Power is marketed through public process via long-term contracts based on long-term average hydrology

Power is allocated through a lengthy public process for each marketing system and many customers have typically received power since project inception. In most cases power has been sold as a bundled product. Reclamation's customers have a high level of interest in ensuring long-term availability of hydro power and there is concern about on-peak versus off-peak price differential and the impact to ratepayers.

Main thing is that each power system is different and one size does not fit all. The capability to integrate wind power differs among regions. Since capability differs equity in allocating integration ability is important. The capability to integrate is not unlimited

Final there is some concern about the impact to system reliability, the long-term product reliability and availability. Reliability councils are grappling with reserve calculations, regulation requirements, load following impacts, and technical interconnection requirements.

There may be some opportunities such as renewable energy partnership between wind and hydro. opportunity for large hydro to become environmentally preferable, opportunity for customers to have firming wind power, opportunity for green tag certification

Alain Corcione- Hydro Quebec Research Institute

Canadian context-62% of energy is hydro, 26% is fossil and 12% is nuclear. Small wind 236 MW installed. Not interconnected east to west. 7.5% of Canadian power is exported to US. Most of population is near border, while hydro is in north.

Hydro Quebec-95% hydro. There is 102 MW of wind on line. RFP has been issued for 1GW more before 2012. 6900 MW of interconnection capacity, 4430 MW with NE USA. Electricity is cheap 3.4 US cents per kWh. Massive resistive heating in a cold climate. Load highly cycled daily and seasonally. Load correlated to wind because wind infiltrates buildings.

Large hydro means coordination of a system of multi-annual, mid-term and short-term reservoirs, interlinked into basin wide management systems that are large. System wide, reservoir management is constrained by reliability issues. Patrimonial power contracts require large amount of power reserved for Quebec and delivered at 2.9 cents.

1200 MW wind site is isolated from grid, there is no transmission. Gaspe Peninsula is 300 MW of load.

Risks for the future are maintaining a sufficient annual water reserve given the changes they are seeing in climate and precipitation and investing in new generation.

Approach is to look at mid-term management modeling. Started with system wide wind/hydro integration to look at interconnections and spot market effects and comparing various generation sources.

SAGE model used which includes wind. Used by Production. Base case was a study of Vermont with the NEPOOL. No possibility, inside Vermont, to manage wind with large hydro plants because they are a thermal system and have limited, highly constrained short term storage. Technically high penetration of wind is possible in Vermont because neighbors have high loads. Economically, wind value depends strongly on NEPOOL spot price. Required price support of 1.32 cents/kWh today.

Second case is base case plus interconnections with Hydro Quebec and coordinated management. Best-case scenario. Perfect correlation of HQ price and Quebec's load was assumed. Selling stored energy when negatively correlated with spot price and combined Quebec's load were favorable. Result was that Hydro-Quebec's reservoirs were able to better optimize Vermont's wind energy value, thereby adding value above NEPOOL spot priced. Value of wind was 22% higher than if it were sold only at NEPOOL spot prices, but a likely outcome in reality will be lower.

Integration of increasing amounts of energy from other generation with the hydro system. Up to certain proportions 10-20% the annual generation profile doesn't bring any value or cost. Didn't include stochastic nature of wind. System wide management is constrained by short-term efficiency and reliability issues. Need to be able to model the electrical limits on the transmission system.

Using SimPower System (Matlab) and HyperSim which is a model of their own grid to look at harmonics. New model development needs to address the capacity reserve and hydraulic balancing of wind output.

Elliot Mainzer -Pricing Desk Manager Bonneville Power Administration

Voluntarily complying with FERC 888. Offering new service called Storage and Shaping Service. Also offering Network Wind Integration Services.

BPA began assessing the costs of integrating wind into the FCPRS two years ago. Developed a Storage and Shaping Service for new wind projects. Analytic and pricing studies are complete. Analysis of day-ahead and within-hour impacts was largely consistent with the findings of the Eric Hirst. BPA established a price of \$6.00/MWh for Storage and Shaping Service, not inclusive of transmission.

Within Hour Impacts-Wind forecasting errors are not correlated with load forecast errors and therefore the incremental contribution to variance from introducing wind into the BPA control area is quite small. Analysis of the data, extended over a longer period of time, and close collaboration with the TBL, verified this finding. Applying the same methodology that the TBL uses to size its control area regulation requirement, we quantified the incremental average regulation requirement from introducing up to 1000 MW of wind into this system. This value was less than 100 MW. 10% capacity required for ancillary services.

Value of surplus capacity-Hirst argued that the BPA system had 6000 MW of surplus capacity. This was judged to be overly optimistic. Under most conditions, BPA does have a healthy surplus of short-term capacity. It gives BPA an advantage in dealing with the "tail events" that result from integrating wind.

When wind generation differs substantially from its schedule in a way that dramatically exacerbates regulation requirements, BPA can lean on its hydro units to remedy the imbalance. Other systems will likely have less of this type of flexibility and will have to carry larger amounts of reserves. Moreover, the 100 MW of regulating capacity does not eat substantially into BPA's overall surplus capacity inventory and therefore its opportunity costs are limited.

Many hours that they are pushing heavy load hour generation into light load hours because of other system constraints. Middle of night run system down to low load factor to 3000 MW because they will get into voltage stability problems. If you are running low at night and get a big wind surge, don't have a lot of ramp down capability because you are running at minimums. During spring putting out a lot of fish flows and running generators full tilt, if you get a big surge of wind, would end up spilling a lot of water.

Can safely sell a service at \$6.00 for shaping and storage units where within hour integration costs are probably less than \$2.00 per MWh.

There has been a transition in thinking inside BPA. Merchant sector collapsed, capital markets collapsed. Average price went from \$400/MWh to \$22/MWh. DSI industry is off line. Suddenly BPA found itself in surplus situation rather than needing augmentation. Decided to try a new service to support renewables instead of buying large quantities of renewables.

Shaping & Storage Service Mechanics-Wind project X interconnected to the BPA control area, schedules and delivers energy into the BPA system on an hourly basis. At the end of each day, PBL averages the scheduled and delivered Peak and Off Peak generation from the project. This amount of power is then redelivered a week later in flat Peak and Off-Peak blocks. The one-week delay allows the end-use customer to plan its system for redelivery volumes and takes the hour-to-hour uncertainty out of the wind generation. Features are very similar to a service provided to BPA by PacificCorp for Wyoming projects and comparable to a service that BPA provides to PGE to integrate the Vancycle Wind Projects.

It is also an attractive service to IOUs outside of their control area. Perfect for a Portland General who has a wind RFP. Real time integration service is of interest to public power customers. No capacity credit and charge them for load following. Credited them on a bill for wind energy they contribute to system and lowers amount of preference power they take. Want to see multiple control areas offering this service. If tail effects are an issue can probably be handled by reserve sharing pools.

Pricing Shaping and Storage-Include minimum generation constraints during low load hours, considered the seasonal capacity headroom and impacts on spill. Dry water years open capacity reserves a bit. They looked at expected price differences between heavy load and light load hours. Impacts on Slice customers are of concern. 22% of power is sold naked

where the customers are responsible for managing the risk. Need to consider down stream parties who may need to absorb downstream impacts from flow swings.

Essential thinking of pricing Storage and Shaping Service is as follows: At any one time, you have two things happening---wind generation coming into the system and an outgoing scheduled redelivery of power from the previous week. To the extent that the amounts of energy entering and leaving the system are identical, BPA does not have to lean on its system capacity to make the redelivery. To the extent that the values differ, BPA must deploy system capacity that can otherwise be used for secondary marketing. We spent considerable time looking at the week- to- week correlation of wind generation and determining how much capacity, on average, we would have to withhold to ensure we could satisfy our net redelivery obligation.

BPA defined an expected case based on the statistics and then chose an appropriate point on the distribution of monthly net redelivery volumes that gave us a statistical edge on the service...so that 8 out of ten times you are winning. We were more conservative during times of the year when the BPA system tends to be relatively constrained. The opportunity costs of withheld capacity were quantified by assessing changes in the volume and diurnal shape of marketable secondary energy and then valuing these MWhs against a forward price curve. BPA also assessed the impacts on our ability to load factor.

The will be escalated annually at the GDP Implicit Price Deflator, same as the Production Tax Credit. Price includes the intra-hour regulation and load-following costs, the opportunity costs of withheld capacity, and an adder for risk. If other utilities can beat BPA price, BPA encourages. Working with our Ops and Real Time groups and the TBL, to closely monitor these costs as we gain experience in making this service over the rest of the rate period through 2006. We have assumed no changes to the rules for generation imbalance with respect to S&S Service. Generators will still be liable for deviations from their schedules.

Parsons: Opportunity cost is related to water in a hydro based system. Not present in a thermal system. Is it market, is it heavy load, is it a surplus pool, is a regulatory cost?

Patrick Quinlan NREL DC Office-Wind Hydropower Connection to Hydrogen

Looking at ways to meet transportation energy sector needs by renewables as oil reserves drop. Projecting 6000 MW of wind in placed by end of 2003. Expected to go to 3 cents on shore 5 cents off shore per kWh by 2012. Low wind speed turbines can take advantage of Class 4-5 wind areas. Low wind will be distributed generation which will be a lot closer to communities and to distribution systems. Looking at floating off shore wind turbines. Off shore potential in Northeast is tremendous within 50 nautical miles from shore at 30 meters depth. There is a 50,000 MW potential along shore. Winooski, VT Hydro Dam. Northern Power systems/Proton. - H2 Fueling station and fuel cell bus. Renewable source: Grid tied hydropower dam. H2 Production fuels vehicles. Hydrogen required for 50% of current fleet with a doubling of efficiency of fuel cells. Approximately 40 million tons/year. Huge increases in resources required to do it. For example, 140 dedicated new nuclear plants. Would have to double nuclear production.

Redoing models for looking at combined wind and hydropower meeting H2 production. Has more granularity than National Energy Modeling System NEMS that provides a very rough approach to wind. Provide options for optimizing outputs of products for both hydrogen and

electricity. Process is less water intensive than energy processes in place now. Water quality is also an issue. Hydrogen is very expensive to transport which means that local/regional electrolyzing is important.

Matt Schuerger: Wind on the Wires

Group is a policy group working out of Minnesota. Working on three areas in the Upper Midwest. Technical, Transmission Planning, and Outreach and Education. Excel Energy did a study with a 4% penetration for wind and found that it would be relatively easy to accommodate.

New study is just getting underway on wind-hydro integration in the Missouri Basin. Study will assess the technical, economic, and institutional opportunities (and barriers) to utilizing hydro generation facilities on the Missouri River system to increase the amount of wind generation capacity integrated into the system.

About 1000 MW of wind power spinning. There is potential for 499,000 MW potential based on average MW. Nameplate capacity about three times that. Currently installed capacity is: Iowa 423 MW, Minnesota 401 MW, Nebraska 14 MW, North Dakota 66MW, South Dakota 44 MW, Wisconsin 53 MW. Goal of 10 percent capacity served by wind power would be about 8000 MW. Very interested in Pick-Sloan integration. Six dams with 2500 MW capacity. Combined storage about 75 MAF, about three times average annual runoff. Western has about 3300 MW of load and 2000 MW thermal generation. 2250 mw near Garrison, 2250 MW east of Oahe and Big Bend, 240 MW north of Gavins Point. 2400 MW north and east of Missouri River and 650 MW north of Big Bend in North Dakota.

Issues included competing purposes for the Missouri River System, increasing operational constraints, existing long-term preference Power contracts, and inter-year variations in power production due to weather.

Tom Murphy Bonneville Power Administration Project Manager for Optimization Project

Goals of FCRPS Optimization and Efficiency Improvement Project are: Better use of Water (Basin Optimization), Better Use of Machines (Plant Optimization), Better Machines (Unit Optimization), Better Inventory Management.

Working on feed forward generation five minute forecast based on past years. As wind comes into system if it degrades forecast, will impair ability to optimize. Are able to calculate lost generation based on inefficient operations. Can adjust based on maintaining the same unit commitment. Working on more sophisticated iteration that can factor in unit commitments. Because each unit has different efficiencies, it is possible to get more generation using less water. This is an information system for system operators. Reclamation and Corps are working on their own optimization schemas now.

Impact of Wind on BPA Operations:

- Better use of Water (Basin Optimization)-Will de-optimize the scheduling of water in the river because the forecast will be less accurate.
- Better Use of Machines (Plant Optimization)-1. Big changes will cause units to cycles on and off. Will cause BPA to put more units on. 2. Small changes will not exactly net out a loss of operating efficiency, As you increase wind, the efficiency curve is

flatter, as you decrease wind, the efficiency curve is exponential and drops off more quickly, so it won't net out.

- Better Machines (Unit Optimization) Same as above.
- Better Inventory Management-Will affect spinning reserve calculations.

Elliot Mainzer-Bonneville Power Administration Transmission Issues

Because of the way that the regional grid is configured S&S requires two wheels-one into and one out of BPA system. Starting with two point to point wheels, the transmission costs can increase the price of S&S Service to as high as \$18/Mh. Developing strategies to manage the transmission costs is a critical challenge facing BPA as they attempt to sell this service to entities outside of our control area. Developing ideas include capping the redelivery volumes at 50% of the project's nameplate rating and potential using NT transmission for imports. This is built into project, when we re deliver, we will never deliver more than 50 MW. When a 100 MW project generates above 50 MW on average for a day, BPA will store the incremental energy about the 50 MW.

Most regional utilities use Network Transmission (NT) rather than Point to Point to import power into their systems. Since the costs of NT are already paid for either by the merchant function or by native load, imports can be consummated at no incremental costs.

PBL has a more complicated relationship to NT than most regional utilities. BPA's power customers, rather than the PBL itself, have the rights to NT transmission. Most IOUs have kept their NT rights rather than sold them like BPA. BPA has an agreement in place with a large group of their customers that allows us to use their NT transmission rights to import power into BPA system on a non-firm basis. Combined with capped redelivery values, this could reduce the cost of S&S Service to as low as \$10.50/MWh delivered. The NT agreement has some excellent features—flexibility, no incremental costs, but the agreement expires in 2011 and is non-firm.

BPA Wind Team Panel:

Steve Inyard-TBL, Kevin Johnson, Lynn Aspaas-Reserves, Mark Johnson, Ian Byrd-Modeling, John Pease, Orville Bloomhart, Steve Kearns-Rates.

Steve Kearns-Large service territory with large amount of flexibility within the hour, week and month. Difficult to model with uncertainty of load and price forecasting. Small amount of wind can be absorbed. HySim Model is regional month average water model with monthly targets using a different set of stream flows historic or forecast. Includes the constraints and the priorities they have. Some of the complexity is due to the Canadian portion of the river system. Hourly Operations and Scheduling Simulator (HOSS). Assumes HLH generation has the highest value so it maximizes that.

Orville Bloomhart-Establishes parameters for typical wind operations. Used a single 100 MW project scaled up to 1000 MW with four years of data. Assessed the number of times they would take in entire amount of wind project and deliver it out to customers.

Kevin Johnson-Worst case was to hold out 1000 MW of capacity to deliver wind that could not be generated. Gave them some capacity credit when the risk of being wrong wasn't so expensive in fall and spring. Balanced the risk over a year.

Ian Byrd-Used the regular study tools to compare scenarios. Took 60 year water data set for a base operation to create a generic year and then laid wind in over that. For that amount of wind, the biggest issue is the capacity restriction. Volatility of load is a smaller issue. In spring have a lot of water to move. Potential for high loads in winter where there are capacity restrictions. There is a very non-linear relationship between capacity restrictions and cost. As wind nameplate increases, there are going to be more times when BPA moves energy to low load hours. Amount of wind to be taken in is uncertain. BPA reduced the capacity of the Hydro system in order to take in the wind generation. In the spring and winter this can be a big issue, particularly in heavy water year. This has a dry year benefit. Effect is to de-rate the system.

Parsons: Avista believes that integrating wind with hydro may be more expensive than integrating with thermal system.

Byrd-There will probably be more hours in wet years that you are forced to spill.

Schuerger: When is hydro no longer absorbable? BPA: Don't know yet.

Quinlan-New technologies are coming along that will provide VAR support for intermittent resources.

BPA-Markets aren't developed yet. BPA has seen 1/3 decrease on contingency reserves this year as people going to self-supplying or other suppliers.

DOE-What benefit is there to hydro system?

BPA-If we get into a dry water year, wind generation will be a good thing. From a revenue perspective, S&S Service has a positive impact on revenues during those dry years. Haven't really looked at anything but cost & value side. Doesn't make sense for PNW for BPA to be only wind integrator. Grant County has also been doing this. Key is to get utilities throughout the region providing S&S services. BPA as an organization is on board with the concept of wind integration. There has been a lot of internal education that has been done to get acceptance.

Keith Nitter -Grant County Public Utility District

Nine Canyon wind plant in BPA's service area. Cost quoted by BPA was \$14 + imbalances, other utilities quoted \$ 50 MW/hr. Grant picked \$10/MWhr. Charged firm transmission cost plus the \$10. Stored wind into their pond. Deliver back approximately seven days back on flat schedule in 1 MW increments during same type of load hours. A few problems. Had a little extra spill because it was a windy day. Typically on those days, while you are spilling, prices are low, so you aren't spilling high price power. One operational oddity-mid-October to mid-November salmon spawns occur during day time. So they reverse load factor—low water in the day to keep them in main channel and high water at night. During those days had some high wind, which cause some units to trip, and caused some spill. In dry years, wind was bad for them. Operating below critical and passing inflows to keep operations at minimum. Douglas and Chelan PUDs also integrating.

John Tande- SINTEF Research Institute Norway

Very different attitude in Norway. Wind is seen as a benefit. Almost all production is from large hydropower plants. Total generation is 118 TWh. Inland consumption in 2002 was 120 TWh. Deregulated Nordic power market with spot prices varying from .10-.30 NOK/kWh largely depending on hydro production. 100 NOK approximate 13 USD. Difficult to obtain permission for new large hydropower plants, hence alternative sources are getting favorable attention. Long Norwegian coastline provides excellent wind conditions. Official goal is 3TWh of wind by 2010. 100 MW of wind is installed, while 7TWh is in planning stages with 1000 MW of capacity within the next 10 years. In Europe and Netherlands there are green credit certificate markets. This is helping wind development in Norway. All Scandinavian countries are on the edge of shortages. Last year it was a very dry year, this year it was another drought. Water levels are lower than last year in the reservoirs.

Wind sites in Norway are along the mid and north coasts of Norway. Wind power in Denmark covers about 15% of the electricity consumption. Transmission system in Norway's wind areas is very weak. Norway does have good wind data relatively, primarily from airport data. Does seem to be a weak correlation between wet years and higher winds. Plus or minus 30% production of hydro and 20% for wind over time. Seasonal variations. Weekly hydro inflow peaks in summer, while demand is down. Wind power production nearly matches the demand line, 95% correlation. This allows hydro power to avoid spillage, which is a complement to hydropower.

Have prepared a case study of integrating 50 MW of wind farm without any AGC & SVC, with a hydropower plant of 150 MW. Thermal capacity of transmission line is 200 MW. They dynamic simulation very that application of SVC or wind turbines with frequency converters security voltage stability, as long as the thermal limit of the line is not exceeded. The hydropower plant may be controlled by an AGC scheme to avoid overloading of the line that would allow a larger wind farm. Simulation model developed includes: time series with consumer load, market price of electricity, inflow to hydro and wind speed. Assumed AGC strategy by control the hydro first and secondary control of wind or control only the wind.

Study findings were: Max wind farm size without AGC and reactive control was 50 MW. With AGC and reactive control a 200 MW wind farm can be supported. AGC of hydropower provides for minimum energy losses. AGC of wind farm only give surprisingly low losses. Significant line losses, but may not payback an upgrade because of capacity factor of wind power. Optimum size of wind farm depends on cost curve.

Good correlation between season wind and load in Norway. Seasonal hydro inflow is opposite to wind in Norway. Integration studies indicate that with proper planning wind development in Norway may save hydro spillage.

Magnus Olsson –KTH Sweden

Good conditions in northern Sweden for wind power. Installed capacity about 32 GW, 1.1% of which is wind and about 50% is hydro. New rules for connection of large-scale wind power to the transmission network require wind power production to be able to decrease their production case of congestions problems in the system. Three options reinforce the transmission system, curtail wind curtailment or store in conventional power plant reservoirs.

Two types of areas in model, northern Sweden with variable hydropower and wind and domestic loads, and southern Sweden with thermal power and industrial loads, with limited transmission between the two areas. Modeled hour by hour. Results of the optimization was that modified hydropower production including wind energy storage and disposal of saved water, modified wind power production, reduced power production from more expensive sources.

It is easier to integrate if both types of plants are owned by same utility in Sweden. If not in the same company, one should assume hydropower decrease production because of transmission limited so that wind power can produce. The stored water in the reservoir belongs to the wind producer.

There are three types of markets. The Nordic spot market that is an hourly day-ahead spot market and Elbas (EL-EX) adjustment market that is a balancing market hour add balancing. Third there is the Swedish regulating market. Balance market where TSO buys load following/regulating power. Bids placed until 30 minutes before the actual hour. There are different prices for upward and downward regulation.

Trading on the post market requires 36-hour forecasts, which is a problem for wind. Two ways to handle sell power on the spot market according to forecasts or coordinate hydropower plants with wind power plants. Has done research on hydropower planning including trade-off between energy and reserve markets with a goal to create a hydropower planning model considering sales on the Nordic spot market and the reserve market, the Swedish regulating market. The second piece of research is generating regulating power price scenarios. This will create a model for the regulating market prices to use when constructing scenario trees. This will be used in optimization models to generate optimal bids to the regulating market.

Final Discussion

- This meeting was unusual because people doing active research and PhDs are the usual participants. There was much more company participation in this meeting. Broader participation is very useful.
- Design of markets and services across US and other countries would be useful to compare in how they accommodate renewable, intermittent resources. There is not general agreement on value of wind to system during dry and wet years. Solutions are specific to the projects.
- Operating experience has been the biggest impediment to utilities. Bureau's idea of pilots in US is a good concept. Case studies of existing integrated projects are very useful.
- Analysis and research of projects where pricing and risk have been assessed are very useful. Work between Western and Bonneville needs to be done on how Bonneville have priced the shaping and storage services and factored in the risk. May be a good opportunity in the Pacific Northwest to have a group focus on this for the region.
- How wind can contribute or detract from ancillary services is an important piece. BPA work is important contribution in this area.
- There is a need to educate regulatory community about what impacts market designs and rates can have on integration of wind.
- There is a need to educate operations and reliability community about the accompanying services needed to support and integrate wind. May want to work with reliability councils in doing this.

- The benefits to hydro from integration of wind need to be defined such as retaining water for fish or recreation.
- Wind should not be treated as something different. Each energy source has a peculiarity. For example nuclear is typically base loaded. Equal treatment is important.
- May also be need to share information on interconnection requirements and how those interconnections are working/lessons learned.
- Infrastructure concerns needs to be addressed.

The Path Forward

- First option is to do nothing.
- Second option is to remain separate in Wind and Hydropower Implementing Agreements.
- Third option is to have a joint Annex between Wind and Hydropower.
- Fourth possibility to continue to have technical experts meeting on specific topics of interest and share that information.
- Fifth possibility would be country studies on what costs and practices are for each country.
- Perhaps generalize to renewables (such as run-of-the-river hydro) integration because there are common characteristics with regard to how these technologies would be considered.
- Perhaps there is a need to go to the ExCo with a one-page recommendation on what to do.
- Sweden and U.S. are interested in approaching the ExCo in forming an Annex on Wind Energy System Integration.
- Hydro's interest is storing power in reservoirs and using that value, while wind's interest is integration into the grid.
- CEATI has a special interest group of operations folks working on items of mutual interest. It would be an easy step to have a meeting on the topic of wind-hydro integration.

Summary of Final Discussion

Future collaboration on wind/hydro integration would be beneficial for countries within both the wind and hydro Annexes. Some of the most important issues that were identified include:

- The need for a forum to share information related to wind/hydro integration. Types of information to be shared includes
 - Sharing of operational experiences
 - Results of case studies
 - Problem formulation and analysis methods
 - Costs, benefits, and detriments of wind/hydro integration
 - Educational outreach to the many affected parties/stakeholders
- The need to understand wind system impacts and costs on the electrical system:
 - Hydro dominated grid
 - Thermal dominated grid
 - Grid with balanced mix of hydro and thermal generators

- Rational, analytic evaluation of ancillary services and costs; define what ancillary services are needed by wind generators and relate to those that can be supplied by hydro facilities
- The need to identify the “true cost” of integrating wind in the utility system (i.e., not what is paid for to integrate wind, but the actual costs incurred)
- The need to study and understand market design and its relation to wind integration in electricity systems.
- The need to involve system operators of hydro facilities, wind facilities, and grid systems into the study of wind/hydro integration. These are the people that run the systems and can be of great assistance in studying the problems and devising and implementing the solutions.
- The need to study and quantify the benefits/detriments to the hydro system of integrating wind energy. For example, what are the benefits/detriments to irrigation, environmental concerns, etc., and does integrating wind with hydro increase or decrease operational constraints?

The following three paths were generally favored for continuation of wind/hydro integration studies, but it was unclear which would be preferred:

1. Formation of an Annex on the Integration of Wind and Hydropower technologies, supported by interested countries from both the Hydropower and Wind Annexes.
2. Continued topical expert meetings jointly sponsored by the Wind and Hydro Annexes.
3. Formation of an Annex on Integration of Wind Energy in the Utility Grid. A subannex or special topic of this Annex could be integration of wind and hydropower systems.

Concerning these three options, it was felt that the first two would provide the best forum for the study of wind/hydro integration. One potential drawback of the third option is that wind/hydro integration might be considered as a low priority issue since it involves additional complexity beyond integration of wind into a thermally dominated utility grid. Furthermore, the third option may be of less interest to the participants from the Hydro Annex.

List of participants											
IEA R&D Wind Annex XI Topical Expert Meeting #41											
November 5-6, 2003, Portland, Oregon, USA											
Last Name	First Name	Affiliation	Address	City	State	Country	Postal Code	Phone	Fax	Email	
1	Forcione	Alain	Hydro-Quebec -IREQ	1800, boul. Lionel-Boulet	Varenes	Quebec	Canada	J3X 1S1	+1 450 652-8361	(450) 652-8905	forcione.alain@ireq.ca
2	Koch	Frans	IEA Implementing Agreement for Hydropower Technologies & Programs	5450 Canotek, Unit 53	Ottawa	Ont.	Canada	K1J 9G3	+1 613 745 7553	(613) 747-0543	fkoch@gvsc.ca
3	Molgat	Louis	Wind and Hydraulic Energy Program CANMET Energy Technology Centre (CETC) -Ottawa	580 Booth St. 13th Floor	Ottawa	Ont.	Canada	K1A 0E4	+1 613 996-4839	(613) 996-9416	lmolgat@nrcan.gc.ca
4	Tande	John Olav G	SINTEF Energy Research	Sem Saelands vei 11	Trondheim		Norway		+47 7359 7200	47 7359 7250	john.o.tande@sintef.no
5	Thor	Sven-Erik	FOI Aeronautics - FFA	Ranhammarsvagen 14	Stockholm		Sweden	172 90	+46 8 5550 4370	46 8 253481	trs@foi.se
6	Olsson	Magnus	Royal Institute of Technology	Teknikringen 33	Stockholm		Sweden	S-100 44	+1 46 87907769	46 87906510	magnus.olsson@ekc.kth.se
7	Aspaas	Lynn	Bonneville Power Administration	905 NE 11th	Portland	OR	USA	97034			lmhart@bpa.gov
8	Bermejo	Sarah	Bonneville Power Administration	905 NE 11th	Portland	OR	USA	97034			skbermejo@bpa.gov
9	Bird	Ian	Bonneville Power Administration	905 NE 11th	Portland	OR	USA	97034	+1 503 230-7510		imbird@bpa.gov
10	Blumhardt	Orville	Bonneville Power Administration	P.O. Box 3621	Portland	OR	USA	97208-3621	+1 503 230-5464	(503) 230-3681	objblumhardt@bpa.gov
11	Kerns	Steve	Bonneville Power Administration	905 NE 11th	Portland	OR	USA	97034	+1 503 230-7542		srkerns@bpa.gov
12	Pease	John	Bonneville Power Administration	905 NE 11th	Portland	OR	USA	97232	+1 503 230 3299		jhpease@bpa.gov
13	Mainzer	Elliot	Bonneville Power Administration	P.O. Box 3621	Portland	OR	USA	97208	+1 503 230 3530		eeainzer@bpa.gov
14	Ingrann	Allan	Bonneville Power Administration	P.O. Box 3621	Portland	OR	USA	97232	+1 503 230 4062		aeingram@bpa.gov
15	Murphy	Tom	Bonneville Power Administration	P.O. Box 3621	Portland	OR	USA	97208	+1 503 230 5527		trmurphy@bpa.gov
16	Lo	Joseph	BPA	P.O. Box 61409	Vancouver	WA	USA	98666	+1 360-619-6053		jolo@bpa.gov
17	Enyeart	Stephen	BPA/TBL	7710 NE Greenwood	Vane	WA	USA	98662	+1 360 619 6059		shenyeart@bpa.gov
18	Jackson	Mark	BPA/TBL	P.O. Box	Vane	WA	USA	98666	+1 360 418 2846		majackson@bpa.gov
19	Knitter	Keith	Grant PUD	P.O. Box 878	Ephrata	WA	USA	98823	+1 509 754 5002		kknitte@gcpud.org
20	Hunt	Dick	INEEL - Hydropower Program	P.O. Box 1625	Idaho Falls	ID	USA	83415-3830	+1 208 526-2825	(208) 526-0969	huntrt@inel.gov
21	Acker	Tom	NREL	1617 Cole Boulevard, MS3811	Golden	CO	USA	80401	+1 303 384-7020	(303) 384-7097	tom_acker@nrel.gov
22	Parsons	Brian	NREL	1617 Cole Boulevard, MS3811	Golden	CO	USA	80401	+1 303 384-6958	(303) 384-7097	brian_parsons@nrel.gov
23	Quinlan	Patrick	NREL	901 D Street, S.W., Suite 930	Washington	DC	USA	20024-2157	+1 202 646-5038	(202) 646-7780	patrick_quinlan@nrel.gov
24	Sale	Michael	Oak Ridge National Laboratory	P.O. Box 2008, MS6036	Oak Ridge	TN	USA	37831	+1 865 574-7305		salemj@ornl.gov
25	Bryan	Karl	US Army Corps of Engineers	P.O. Box 2870	Portland	OR	USA	97208-2870	+1 503 808-3894	(503) 808-3891	karl.a.bryan@usace.army.mil
26	Linke	Deborah	US Bureau of Reclamation	D-5400, Box 25007	Denver	CO	USA	80225	+1 303 445 2923		dlinke@do.usbr.gov
27	Ahlgriem	Jim	US Department of Energy	EE-2B Forestal Building	Washington	DC	USA	20585	+1 202 586-9806	(202) 586-5124	jim.ahlgriem@ee.doe.gov
28	Schuerger	Mathew	Wind on the Wires	1000 Independence Ave., S.W.	Washington	DC	USA	20585	+1 202 586-9806	(202) 586-5124	mathschuerger@earthlink.net
				P.O. Box 16129	St. Paul	MN	USA	55118	+1 651 699 4971	(651) 698-2148	
				Hannele Hoitinen							
Proceedings will be distributed to											
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				Inst. för Eteknik							
				412 96 Göteborg							
				Chalmers							
				Royal Institute of Technology							
				Teknikringen 33							
				Stockholm							
				Sweden							
				S-100 44							
				Gonzalo Piemavieja Izquierdo							
				Playa de Pozo Izquierdo s/n							
				POZO IZQUIERDO							
				E-35119							
				Santa							
				Spain							
				Jayson Antonoff							
				grnNRG Consulting							
				Borgergade 25, 1 tv							
				9000 Aalborg							
				Denmark							



Tom Acker
Alain Forcione

Magnus Olsson

Sven-Erik Thor
Deborah Linke
Sarah Bermejo

Ian Bird

Lynn Aspaas

John Pease
Brian Parsons

Elliot Mainzer

Kevin Johnson

Frans Koch
Mike Sale
Allan Ingrann

Steve Enyeart
Jim Ahlgrimm

Mark Jackson

Dick Hunt
Keith Knitter

John Olav G. Tande

Louis Molgat

Mathew Schuerger
Patrick Quinlan

Missing on picture

- Orville Blumhardt
- Steve Kerns
- Tom Murphy
- Joseph Lo
- Karl Bryan