Integration of Wind and Hydropower Generation in America

Mark F. Bielecki and Jason J. Kemper
Graduate Research Assistants, Mechanical Engineering

T. L. Acker
Associate Professor, Mechanical Engineering

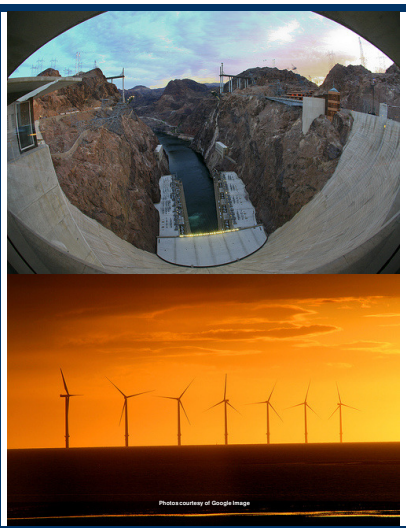
NORTHERN ARIZONA UNIVERSITY

Sustainable Energy Solutions

1. Intro to Wind/Hydro

In 2003, the U.S. Department of Energy (DOE) began studying the potential to "integrate" wind and hydropower resources, essentially investigating the ability, the impacts to, and opportunities for hydropower in helping balance wind power on the grid. Subsequently, in 2004, the International Energy Agency (IEA) established "Task 24" under the auspices of the IEA Wind Implementing Agreement to investigate the same topic. Task 24 is entitled "Integration of Wind and Hydropower Systems.," for which the DOE is a participant and the National Renewable Energy Laboratory (NREL) is the Operating Agent. The U.S. participation in the work of Task 24 is through contributing case studies of wind/hydro integration. The purpose of this poster is to summarize some results from these studies, as well as from other related studies (not part of Task 24) that have been conducted in the U.S.

Systems that contain significant amounts of hydro generation have the possibility to incorporate substantial amounts of wind power into their balancing area through careful planning and active balancing. Depending on its characteristics, a given hydropower plant may be able to offer short-term flexibility for regulation or load following to offset the stochastic nature of wind and limitations in its forecasting, and even offer longer term storage of shifting of energy delivery.



2. Study Methodologies

Each individual integration study is tailored to the specific characteristics of the system being modeled (i.e. geographic location, generation resources, planning timeframes, market characteristics, etc.), to answer the specific questions of the organization conducting the study. However, the methodologies used for most studies address a common set of questions using similar techniques.

Figure 1 displays a "matrix" used to help compare and characterize the results from the various integration studies, developed as part of the work plan of Task 24 [Söder, 2005]. Specific topics reviewed in this poster are:

- Very long term correlations between the production of wind and hydropower;
- Pumped hydro; and
- Wind integration costs and reserve requirements and how these might be influenced by varying rates of hydropower production, penetration levels, and the ability to shed wind.

For this poster, four relevant case studies were reviewed:

- Sacramento Municipal Utility District (SMUD)
- Western Area Power Administration (WAPA)
- Idaho Power
- Avista Corporation

The Grant County Public Utility District, No. 2, of Washington State has also conducted a study, focused on wind power impacts on hydropower constraints. Their results are presented on another AWEA poster submitted by NAU.

Study conducted by:							
Geographic area of study:							
Power system characteristics:							
Load				Conventional generation	Interconnection	Wind power	
Peak (MW)	Min (MW)	TWh/a		Capacity (MW)	Capacity (MW)	MW	TWh/a
Other relevant characteristics of power system:							
Characteristics of system planning:							
Description of market:							
Integration time frames of importance:							
Yes/No	Time Frame						
	Inertial response, system dynamics, grid stability, LVRT, PSS, V-Reg						
	Regulation, AGC						
	Load following, introhour ramping; economic dispatch						
	Unit commitment and day-ahead scheduling; economic utilization of resources						
	Resource and capacity planning; reliability						
Set up							
A	Aim of study		1 what happens with x GWh wind 2 how much wind is possible				
M	Method to perform study		1 add wind energy 2 wind also replaces capacity 3 optimal system design				
S	Simulation model of operation		1 deterministic simulation, one case 2 deterministic simulation several cases 3 Stochastic simulation several cases				
Simulation detail							
R	Resolution of time		1 day/week 2 hour 3 minute/second				
P	Pricing method		1 costs of fuels etc 2 prices for trading with neighbours 3 market actor simulation 4 market dynamics included				
D	Design of remaining system		1 constant remaining system 2 optimized remaining production 3 optimized remaining transmission 4 perfect trading rules				
Uncertainty and balancing							
I	Imbalance calculation		1 only wind 2 wind+load 3 wind+load+production				
B	Balancing location		1 dedicated source 2 from the same region 3 also outside region				
U	Uncertainty treatment		1 transmission margins 2 hydro inflow uncertainty 3 load uncertainty (persistence) 4 best possible wind forecasts 5 load forecasts considered 6 thermal power outages considered				
Power system details							
G	Grid limit on transmission		1 no limits 2 constant MW limits 3 voltage 4 N-1 criteria 5 dynamic simulation				
H	Hydro power modeling		1 head height considered 2 hydrological coupling included (including reservoir capacity) 3 hydrological restrictions included 4 hydro optimization considered 5 consider most relevant aspects of affected hydro resources				
HC	Hydro capacity service		1 interaction with hydro resources not significant 2 real-time integration with impact of wind variability on system managed with hydro 3 capacity service: addition of capacity value through redelivery of wind energy at a later time				
T	Thermal power modeling		1 ramp rates considered 2 start/stop costs considered 3 efficiency variation considered 4 heat products/cons.idered				
W	Wind power modeling		1 few wind speed time series 2 many wind power time series 3 time series smoothing considered				

Figure 1 – A "matrix" used to aid in comparing integration studies.

3. Case Studies

Western Area Power Authority (WAPA):

EnerNex conducted a wind integration feasibility study, funded by NREL, to determine the amount of wind generation that could be integrated into the Upper Great Plains Region (UGPR) control area of WAPA [Zavadil, 2006]. The effects of incrementally increasing levels of wind capacity of 80, 100, 250, 500, and 1000 MW were analyzed. This compares with a peak system load of 2700 MW for the region. A primary goal of the study was to investigate the existence of any correlation between wind trends in the Dakotas and water runoff (and hence hydro resources) in the Missouri River Valley Basin. Annual capacity factors for the five cases ranged from 42-44%. By season, the capacity factors were lowest in the summer months and greatest in the spring and fall. The average daily profiles were generally flat with a decline late in the day, especially in the summer months. The hydro resources available to this control area are in the Missouri River Valley Basin. Long term runoff data for the Missouri River above Sioux City, Iowa was provided by the Army Corp of Engineers for the period of 1964-2003.

It was discovered that small to modest inverse correlations (R = -0.25 to -0.26) were found in comparing 2 and 3 year running averages of wind velocities and hydro runoff. Thus, about 60% of the time, the departure of the average wind velocity and runoff from their 2 or 3 year running averages were of different sign. This could indicate synergy in integrating these resources over prolonged droughts or periods of low wind since a 2 or 3 year period in which the hydropower output was low is more likely to have occurred during a period with higher than average wind power output and vice versa. It could also indicate a leading or lagging statistical relationship between these resources. This led to the strongest statistical correlation discovered in the study. In comparing long term runoff to wind velocity data, the wind speed was found to lead runoff via an inverse correlation (R = -0.4). The strength of this inverse correlation is apparent in Figure 2, which presents runoff and wind speed departures for one year averages with a one year lead applied to the wind departures. This can be compared with Figure 3 presenting similar information without the lead. Thus, for 67% of the comparison points, low wind speed years were preceded by above average runoff years. The implications for this correlation are important for managers with sufficient storage capacity and flexibility in its use: years with higher than average runoff could be used to allow hydro operators to fill reservoirs in advance of an upcoming year with diminished wind output.

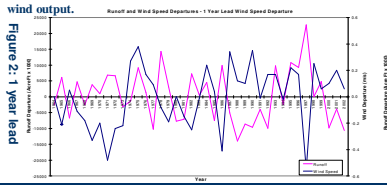


Figure 2: 1 year lead

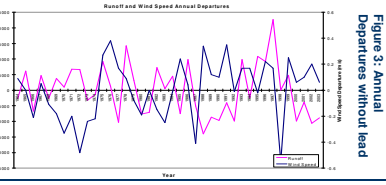


Figure 3: Annual Departures without lead

Idaho Power:

In 2007, EnerNex and Idaho Power completed a wind integration cost and impact study that investigated four different wind power penetration levels (nameplate capacity / system peak load) ranging from 10% to 39% over three different hydrologically representative years (wet, dry, and average precipitation levels) [EnerNex, 2007]. Idaho Power, in a typical year, generates 53% of its energy from eighteen different hydroelectric power plants, which it owns. As of 2007, Idaho Power had already committed to adding 384 MW of wind generation (12.5% penetration). Expected capacity factors ranged from 24-30%, which may be on the low end of wind projects but this may be expected when viewing a map of the states resources. Figure 4 shows that there is abundant class 2 and 3 wind but only modest areas greater than class 4.

The study concluded that Idaho Power's upper limit for integrating wind power (without major investment in additional resources) is somewhere between 20% and 29% (600 and 900 MW of nameplate capacity). Furthermore, the average precipitation year resulted in the highest wind integration costs as shown in Table 1. The integration costs were expressed as a percentage of the energy price for the year rather than $/MWh since the energy prices varied greatly from year to year. During water shortages, hydro facilities often are operated at minimally allowable release levels. Thus, maintaining down-ramping capability forces operation of hydro facilities above these optimized (minimum) release levels. On the other hand, during periods of high water, hydro facilities are often operated at capacity to avoid spillage. Thus, maintaining up-ramping capability forces operation of hydro facilities below these optimized (maximum) release levels and increases the possibility of spillage and increased generation during low load hours. Therefore, in years when both extreme hydrologic conditions are experienced, maintaining both up and down- direction reserves creates problems and integration costs may be highest. An important assumption for this study was that there was no possibility for curtailing wind production. This resulted in bi-directionally equivalent ramping requirements at all times. The same assumption was not made in the comparable Avista case study presented below.

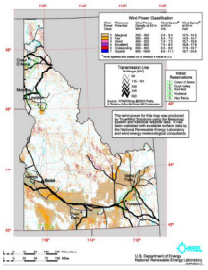


Figure 4: Idaho Wind Resource Map

Table 1: Amended Summary Results from Idaho Power 2007

Wind Capacity	System Penetration	Low Hydro	Avg. Hydro	High Hydro
(MW)	(as % peak load)	(cost as % energy price)		
300 MW	10%	18.4%	16.6%	11.6%
600 MW	19%	16.0%	22.9%	17.1%
900 MW	29%	18.2%	29.6%	21.9%

Sacramento Municipal Utility District:

The 2008 study conducted by EnerNex Corporation for the California Energy Commission focused on the impacts to SMUD that four proposed penetration levels of wind generation would have on fast regulation requirements, equivalent capacity values, and integration costs [Zavadil, 2008]. SMUD currently has 688 MW of hydro with a proposed 400 MW pumped hydro storage facility called Iowa Hill. Wind penetration levels assessed were 102, 252, 453, and 855 MW (Cases 1-4, respectively), which cover up to about 20% of peak system load. Wind installations in Cases 3 and 4 covered a greater geographic diversity as well. Each penetration case was conducted with and without the hypothetical Iowa Hill pumped hydro facility. Additionally, each case was assessed with consideration of state incentives gained through the Participating Intermittent Resources Program (PIRP). Figure 5 shows the integration cost results for the various cases. The study concluded that integration costs are a maximum for Case 2, but generally decrease with greater penetration levels and geographic diversity. The addition of the hypothetical Iowa Hill pumped storage facility decreased integration costs in most scenarios.

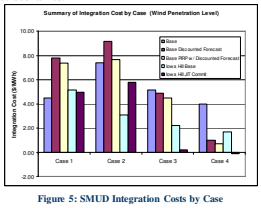


Figure 5: SMUD Integration Costs by Case

Avista Corporation:

The 2007 study conducted by EnerNex Corporation for Avista considered the integration of wind into their hydro-dominated control area in the Pacific Northwest [EnerNex, 2007]. Penetration levels of 100, 200, 400, and 600 MW, which span 5-30% of the control area's peak load were considered. The study included models of three scenarios. One of these was based on the optimization of hydro resources including available storage and flow constraints. Another was focused on pre-scheduling of hydro one hour ahead of time to exploit the highest value hours. The third scenario was based on real-time operations that make use of current wind and load forecasts. The penetration scenarios were also assessed under conditions of low, average, and high availability of hydro. Integration cost results are shown in Table 2. The study also concluded that the altering the timing of market transactions from 1 hour ahead to 5-10 minutes ahead, as well as improved coordination between wind sites and the area control center, would reduce integration costs. Improved coordination would allow for wind curtailments when necessary.

A significant component of this study was to investigate the impacts of using some portion of the available hydro as additional reserves required for wind integration. Avista typically uses hydro during peak load hours, and any lost revenue or "opportunity cost" incurred by dedicating some portion of this hydro to balance wind was included as an integration cost. Figure 6 shows the impacts of keeping 100 MW of hydro available as reserve for wind generation (light blue) as opposed to the standard method of using all available hydro during peak load hours (dark blue). The red line shows the market price for 5 different hour categories of a single day (abscissa shows peak, shoulder peak, and off-peak hours). For this example, there is an opportunity cost of $3500 over the 5 hours for keeping 100 MW of available hydro as reserves for wind instead of using all hydro during peak hours.

Table 2: Amended Summary Results from Avista 2007

Wind Capacity	System Penetration	Low Hydro	Avg. Hydro	High Hydro
(MW)	(as % peak load)	(cost as % energy price)		
100 MW	5%	3.3%	4.8%	7.7%
200 MW	10%	14.0%	11.2%	13.2%
400 MW	20%	15.7%	10.2%	9.7%
600 MW	30%	19.4%	13.8%	14.9%

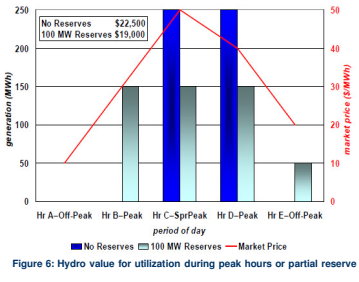


Figure 6: Hydro value for utilization during peak hours or partial reserve

4. Conclusion

Shorter-term scheduling concerns will become increasingly important with large wind penetration levels. Wind/Hydro integration can provide increased flexibility in both long and short-term planning.

Coordination between wind and hydro production will vary between control areas due to specific logistical and financial considerations. However, the ability to curtail wind production during extreme events will influence the wind integration costs. One such event as reported by the Oregon Environment News occurred on July 5, 2008 forcing Bonneville Power Administration to spill large amounts of water when miscommunication led to insufficient wind curtailment. Maintaining unnecessary down-ramping hydro capability to cover a lack of wind curtailment capability would be especially pronounced during low and average hydro production years. Thus, comparing the tables from Idaho Power and Avista, the low and average hydro production years' integration costs are much higher when wind curtailment is not allowed.

Results from SMUD and Public Service Colorado (not presented here) indicate that pumped hydro storage decreases integration costs.

There may be synergistic inverse correlations between wind and hydro production over periods between 1-3 years as found in the WAPA case study. Such correlations deserve more investigation at other locations, but were not significant at shorter, seasonal periods in the Missouri River Valley.

References:

EnerNex Corporation. March, 2007. Avista Corporation Wind Integration Study Final Report.

EnerNex Corporation and Idaho Power Company. 2007. Operational Impacts of Integrating Wind Generation into Idaho Power's Existing Resource Portfolio.

Söder, L. and Holttinen, H. On methodology for modeling wind power impact on power systems. Int. J. Global Energy Issues, Vol. 29, Nos. 1-2, 2008.

Zavadil, R. 2006. WAPA Wind Integration Study, EnerNex Corporation, Knoxville, TN. August.

Zavadil, R. 2008. Wind Integration Study for the Sacramento Municipal Utility District. California Energy Commission, PIER Renewable Energy Technologies Program. CEC-500-00-034.