Wind Integration Studies

PSE currently operates two wind projects: one in BPA's control area (the Hopkins Ridge project) and one in PSE's control area (the Wild Horse project). Experience and analytical studies have helped us understand some of the economic and operating effects of increasing the wind portion of our resource portfolio, which have been incorporated in this IRP planning process.

The costs used, based on Phase 4 evaluations by Golden Energy Services (Golden) of wind costs for our power system, assume a significant portion of the wind generation will be connected directly to our system (probably more than will actually be interconnected). In brief, we estimate wind integration—which includes added regulation due to wind generation, shifts in operating reserve due to wind generation, intra-hourly wind generation variability and day-ahead wind generation variability—will cost $5.90/MWh in 2007, and will escalate at 2.5% per year.

The costs projected in this IRP incorporate some future uncertainty. However, they do not specifically incorporate the effects of two regional events that might affect costs: (1) a current study by BPA and the Northwest Power and Conservation Council on the impact of integrating large quantities of wind power into regional utilities systems, particularly services not currently included in utility open access transmission tariffs; and (2) the recently enacted Washington RPS, which will likely require adding more wind to the region's generating portfolios—and result in higher costs.

I. Managing Variable Output

Unlike other conventional generation resources, wind energy has a relatively high degree of short-term variability. Variability itself is not a key operational issue. Rather, we are concerned about the inability of forecasts to predict that variability.

To ensure our electric system meets industry reliability standards, we must effectively manage short-term uncertainty. Therefore, we will need to gain greater real-time operational flexibility from the non-wind portions of our power system. Most of this is currently provided by our contracted share of the five Mid-Columbia hydroelectric projects—flexibility we currently use to manage load, real-time underruns or overruns, protect against thermal resource outages, and maintain constant frequency within our service territory.

To supplement these Mid-Columbia projects, we can depend on the Baker River hydro plants and at times our simple-cycle combustion turbines. The Baker River plants offer considerable flexibility, especially with the new control systems and operating parameters required by the new project license. Also, at least four of our combustion turbines can be on-line quickly enough to add flexibility when needed.

II. Integration Studies Overview

While much has been written about wind generation, only in the last few years have coordinated attempts been made to identify and quantify the short-term operating effects of large-scale wind farms on utility power systems. In 2003, we asked Golden to help evaluate these operating effects on our power system. Its August 2003 report, *Short-term Operational Impacts of Wind Generation on the Puget Sound Energy Power System* (the Phase 1 report), presented its findings.

In December 2003, we asked Golden to (1) expand on the results of Phase 1, and (2) develop information to help us evaluate wind resource bids. This Phase 2 analysis (included as Appendix D to PSE's 2005 plan) built on Phase 1 using actual wind resource data from a Columbia Basin wind project, and simulated wind resource data developed in Phase 1 for a proposed wind project near Ellensburg, Washington. Phases 1 and 2 analyzed the effect on PSE of

- regulation due to wind generation
- shifts in operating reserve due to wind generation
- intra-hourly wind generation variability
- day-ahead wind generation variability

In late 2004, PSE asked Golden to expand on Phase 2 work using detailed historical wind generation data and associated wind generation forecasts from an operating Northwest wind farm. The goals for this Phase 3 included

- evaluate PSE's short-term wind integration costs using differing amounts of available hydro capacity
- quantify the benefits of developing more accurate short-term wind generation forecasts
- incorporate expanded datasets of historical Northwest regional power prices

In the fall of 2006, PSE asked Golden for additional wind integration cost studies incorporating our existing capacity from Hopkins Ridge and Wild Horse. We also asked for help in evaluating potential new wind resources for our IRP process. A primary goal of Phase 4 was to investigate benefits associated with acquiring wind generation capacity at different physical locations within the Northwest region. Another goal was to update the wholesale pricing assumptions used in Phase 3 to reflect higher natural gas prices.

Figure G-1 shows Phase 4 results: the cost of integrating various levels of wind power into the PSE system, and the effect of adding increasing amounts of wind generation to our system. Not all this wind power will be connected directly to our system, but this provided a conservative means of analyzing integration costs in light of current uncertainty.

Results show that the greater the amount of wind generation, the higher the cost per megawatt-hour (MWh). For example, generating 207.3 MW in 2015 would cost $6.39/MWh. If PSE generated 630 MW in that same year, the cost would rise to $7.81/MWh.

Figure G-1
Puget Sound Energy - Wind IRP Studies
2007 - 2016

Year	PSE Mid-C Net Capacity (MW)	Wind Capacity in the PSE Control Area					Wind Capacity in the PSE Control Area					Wind Capacity in the PSE Control Area				
		Net Capacity (MW)	DA Cost ($/Mwh) 1400 MW	HA Cost ($/Mwh) 207.3 MW	Reg/O.R. ($/Mwh) 207.3 MW	Tot Cost ($/Mwh)	Net Capacity (MW)	DA Cost ($/Mwh) 1900 MW	HA Cost ($/Mwh) 360 MW	Reg/O.R. ($/Mwh) 360 MW	Tot Cost ($/Mwh)	Net Capacity (MW)	DA Cost ($/Mwh) 1900 MW	HA Cost ($/Mwh) 630 MW	Reg/O.R. ($/Mwh) 630 MW	Tot Cost ($/Mwh)
2007	967	207.3	2.44	2.38	0.16	4.98	360.0	2.58	2.55	0.16	5.28	630.0	0.00	0.16	0.00	0.16
2008	967	207.3	2.89	2.80	0.16	5.85	360.0	3.02	3.01	0.16	6.19	630.0	0.00	0.16	0.00	0.16
2009	951	207.3	2.98	2.83	0.16	5.98	360.0	3.13	3.05	0.16	6.34	630.0	0.00	0.16	0.00	0.16
2010	869	207.3	2.70	2.53	0.16	5.39	360.0	2.83	2.74	0.16	5.73	630.0	0.00	0.16	0.00	0.16
2011	839	207.3	2.52	2.34	0.16	5.01	360.0	2.65	2.54	0.16	5.35	630.0	0.00	0.16	0.00	0.16
2012	602	207.3	3.01	2.79	0.16	5.97	360.0	3.12	3.16	0.16	6.44	630.0	0.00	0.16	0.00	0.16
2013	540	207.3	3.13	3.00	0.16	6.29	360.0	3.20	3.44	0.16	6.80	630.0	0.00	0.16	0.00	0.16
2014	540	207.3	3.21	3.10	0.16	6.48	360.0	3.28	3.56	0.16	7.00	630.0	0.00	0.16	0.00	0.16
2015	540	207.3	3.21	3.02	0.16	6.39	360.0	3.27	3.47	0.16	6.90	630.0	0.00	0.16	0.00	0.16
2016	540	207.3	3.22	2.94	0.16	6.32	360.0	3.28	3.36	0.16	6.81	630.0	0.00	0.16	0.00	0.16

Figure G-2 demonstrates how we determined the integration costs we used in our analysis. We started with the Total Cost ($/MWh) from each level of wind. Then we assumed:

- a total of 207 MW generated during the first two years
- adding another wind plant in 2009 for a total of 360 MW (for four years)
- adding two more projects in 2013 for a total of 630 MW (for four years)

The last column "USE" presents a least-squares fit using a 2.5% escalation factor.

Figure G-2
Amount of Wind in PSE Control Area
(Total integration costs, BPA & PSE)

	207 MW	360 MW	630 MW		Cost Steps	USE Est @ 2.5%
2007	$ 4.98	$ 5.28	$ 5.66	---->	$ 4.98	$ 5.90
2008	$ 5.85	$ 6.19	$ 6.63	---->	$ 5.85	$ 6.05
2009	$ 5.98	$ 6.34	$ 6.79	---->	$ 6.34	$ 6.20
2010	$ 5.39	$ 5.73	$ 6.18	---->	$ 5.73	$ 6.35
2011	$ 5.01	$ 5.35	$ 5.79	---->	$ 5.35	$ 6.51
2012	$ 5.97	$ 6.44	$ 7.20	---->	$ 6.44	$ 6.68
2013	$ 6.29	$ 6.80	$ 7.68	---->	$ 7.68	$ 6.84
2014	$ 6.48	$ 7.00	$ 7.92	---->	$ 7.92	$ 7.01
2015	$ 6.39	$ 6.90	$ 7.81	---->	$ 7.81	$ 7.19
2016	$ 6.32	$ 6.81	$ 7.69	---->	$ 7.69	$ 7.37

III. Comparison of Studies

In early 2006, Brian Parsons of the National Renewable Energy Laboratory presented a paper entitled *Grid Impacts of Wind Power Variability: Recent Assessments from a Variety of Utilities in the United States*.[1] The paper summarized results from several studies conducted by other entities to quantify short-term effects, including regulation, hour-ahead (load following), and day-ahead (unit commitment) impacts.

While these categories match up fairly well with those analyzed in our Phase 4 study, the results may not be directly comparable due to differing wind penetration levels and utility resource portfolios. To make the results somewhat more consistent, PSE's Phase 4 costs are based on locating all the generation in our control area.

Figure G-3
Short-Term Operational Costs of Wind Generation
on Large Utility Power Systems

Date	Study	Wind Capacity Penetration (%)	Total Operating Cost Impact ($/MWh)
May-03	Xcel-UWIG	3.5	$ 1.85
Sep-04	Xcel-MNDOC	15	$ 4.60
Jun-03	We Energies	4	$ 1.90
Jun-03	We Energies	29	$ 2.92
Jun-05	PacifiCorp	20	$ 4.60
Apr-06	Xcel-PSCo	10	$ 3.72
Apr-06	Xcel-PSCo	15	$ 4.97
Apr-06	Xcel-PSCo (2)	20	$ 8.87
Jan-07	PSE Phase 4	10	$ 5.50

[1] Co-authored by Brian Parsons and Michael Milligan, National Renewable Energy Laboratory; J Charles Smith, Utility Wind Integration Group; Edgar DeMeo, Renewable Energy Consulting Services, Inc.; Brett Oakleaf, Xcel Energy; Kenneth Wolf, Minnesota Public Utilities Commission; and Matt Schuerger, Energy Systems.