Integration of Variable Energy Resources

Contents

The purpose of this appendix is to provide an update on the advances in the area of variable energy resource integration and assess the system's ability to meet ancillary service requirements for PSE system load and wind within the PSE balancing authority (BA). This appendix includes a broad discussion of PSE wind assets and their characteristics, and introduces key concepts around ancillary services. Modeling results are discussed in some detail to address the ancillary service requirements for wind projects considered in the 2020 IRP base case portfolio.

1. Overview

Wind Development in the Pacific Northwest

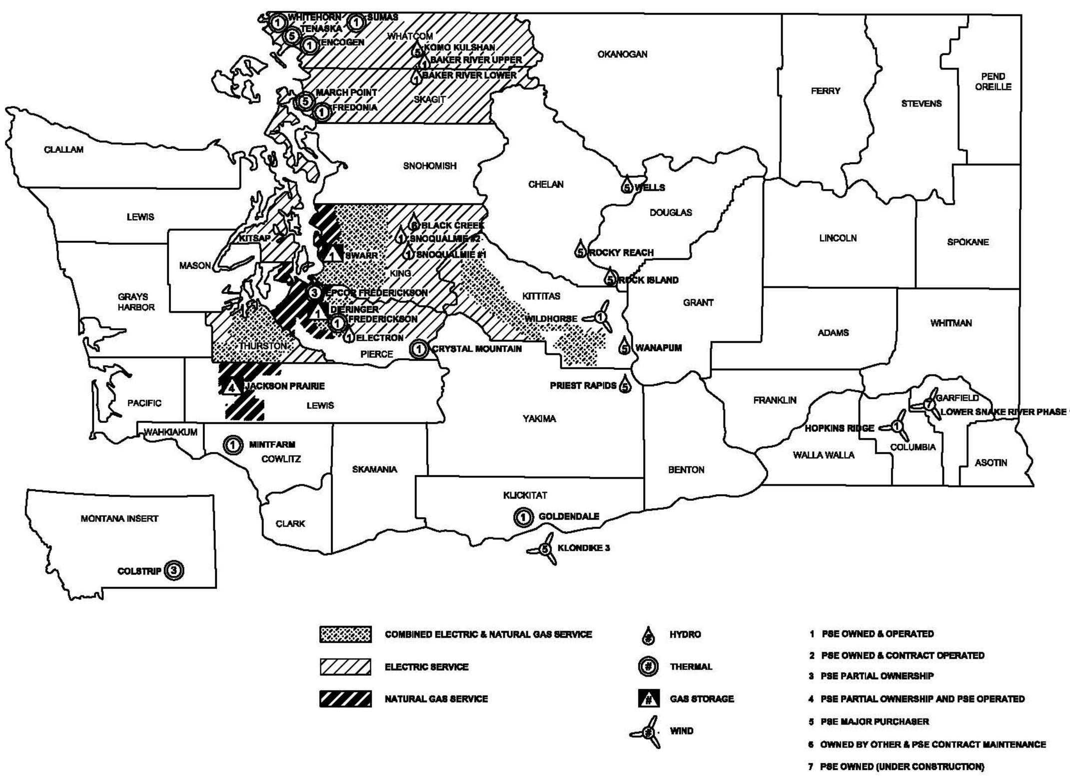
As of December 2010, there are over 4,700 MW of installed wind capacity in the Pacific Northwest including Washington, Oregon, Montana, and Idaho. Over 3,000 MW of installed wind capacity is interconnected to BPA's BA. There are also significant amounts of wind in various stages of permitting and approval process as well as under construction. The majority of installed wind capacity within the Northwest exists within Washington and Oregon and is heavily concentrated along the Washington-Oregon border in the Lower Columbia region. PSE's wind assets, however, are located in central and southeast Washington.

PSE Wind Resources

PSE currently owns and operates two wind projects, Hopkins Ridge and Wild Horse, with a combined capacity of 430 MW. The Hopkins Ridge wind project, located in southeast Washington, has a nameplate capacity of 157 MW and began commercial operation in November 2005. The Wild Horse wind project is located near Ellensburg in Central Washington and is comprised of 149 turbines with a nameplate capacity of 273 MW. The Wild Horse wind project has been online since late 2006. The capacity factors of both Hopkins Ridge and Wild Horse wind projects are around 30 percent. Additionally, PSE entered into a long-term power purchase agreement (PPA) for 22.1 percent (50 MW) of the Klondike III wind plant located in the Lower Columbia River Gorge region. PSE is currently in the process of constructing the 343 MW Lower Snake River Phase I (LSR I) wind facility located in Columbia and Garfield counties in Washington state. LSR I is scheduled to come online in 2012. Figure G-1 shows the proximity of PSE wind projects relative to PSE's service territory.

The Wild Horse wind project is interconnected to the PSE BA, and PSE is responsible for managing the variable output. Both Hopkins Ridge and Klondike III wind projects are interconnected to BPA's BA and as a result, BPA provides integration services to manage the variable output of wind and delivers the hourly scheduled amount of wind generation to PSE's system.

Figure G-1
Map of PSE Service Territory



Third-Party Wind Resources

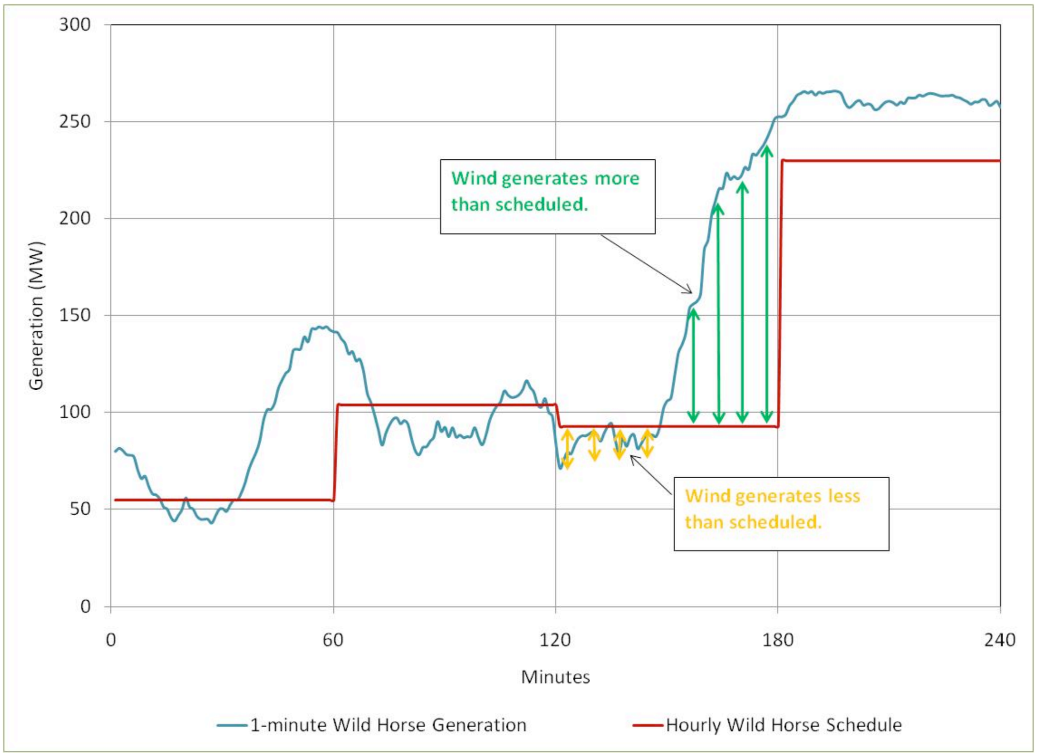
In addition to balancing the output from the Wild Horse wind project, PSE must also manage the output from third-party wind projects. Third-party wind projects are owned and operated by other entities and although they are interconnected to the PSE BA, they serve load outside the BA. PSE is responsible for delivering the scheduled amount of third-party wind to the sink BA regardless of actual wind power output. Effectively, third-party wind in the PSE BA is operationally indistinguishable from PSE-owned wind assets. The Vantage wind project, located in Central Washington, with a nameplate capacity of 96 MW, is the only third-party wind project interconnected to the PSE BA. PSE is currently in the process of ensuring full cost recovery of all wind integration services provided to third-party wind under the Open Access Transmission Tariff (OATT).

2. Variability and Uncertainty of Wind Output

Wind generation is an intermittent and non-dispatchable generation resource. The two primary challenges associated with integrating wind power into the bulk power system are the variability derived from the minute-to-minute natural volatility of wind as well as the uncertainty associated with accurately forecasting the wind output. While the variability can be managed similarly to managing PSE's load, the unpredictable nature of wind creates uncertainty. There can be large differences between the short-term wind generation forecast for the hour-ahead and day-ahead time frames compared to actual generation. Like short-term deviations in actual load, the natural variability inherent in minute-to-minute wind speed contributes to the need for instantaneous balancing of the output. Even with a perfect forecast for the hour such that the hourly forecast equals the hourly average generation, the output within the hour may vary above and below the hourly forecast. An example of the interaction between the one-minute Wild Horse wind generation output in comparison to its hourly scheduled output is presented in Figure G-2. The data used in the graph represent actual project output from December 14, 2010.

Figure G-2

Wild Horse Actual and Scheduled Generation from 12/14/10



To help manage the uncertainty in wind generation output, PSE constracts with a vendor to provide real-time wind generation forecasts across different time horizons. The vendor utilizes the latest state-of-the-art forecasting techniques and latest data feeds from the wind projects to ensure that the forecast error is minimized. The error associated with forecasting generally increases across the next several hours into the day-ahead time frame, which makes unit commitment decisions difficult and drives the need to carry ancillary services capable of making up for deviations in forecasted and actual generation.

3. Characteristics of Variable Energy Resources

Temporal and Seasonal Wind Characteristics

Wind generation varies year to year, by season as well as hour of day. Figure G-3 depicts the average monthly capacity factor for the Wild Horse and Hopkins Ridge wind projects from 2007 to 2010. For much of the year, their monthly capacity factor shapes track one another fairly closely. Both projects show higher generation for March through June.

Figure G-3
Wild Horse and Hopkins Ridge Monthly Capacity Factors

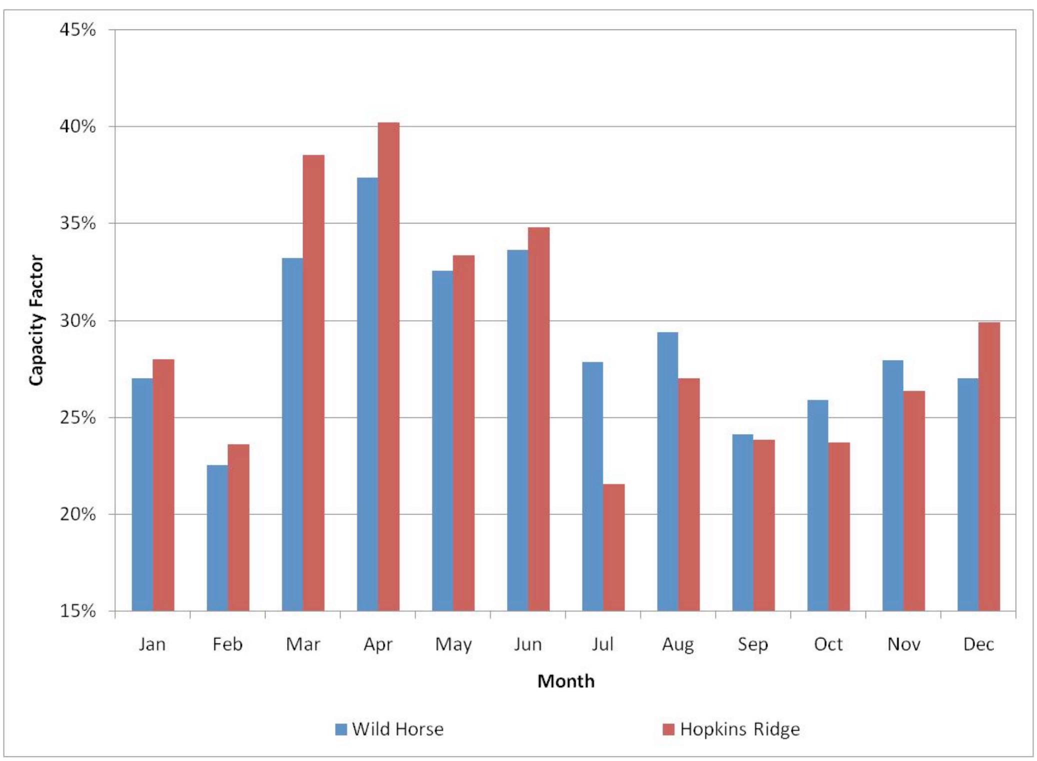
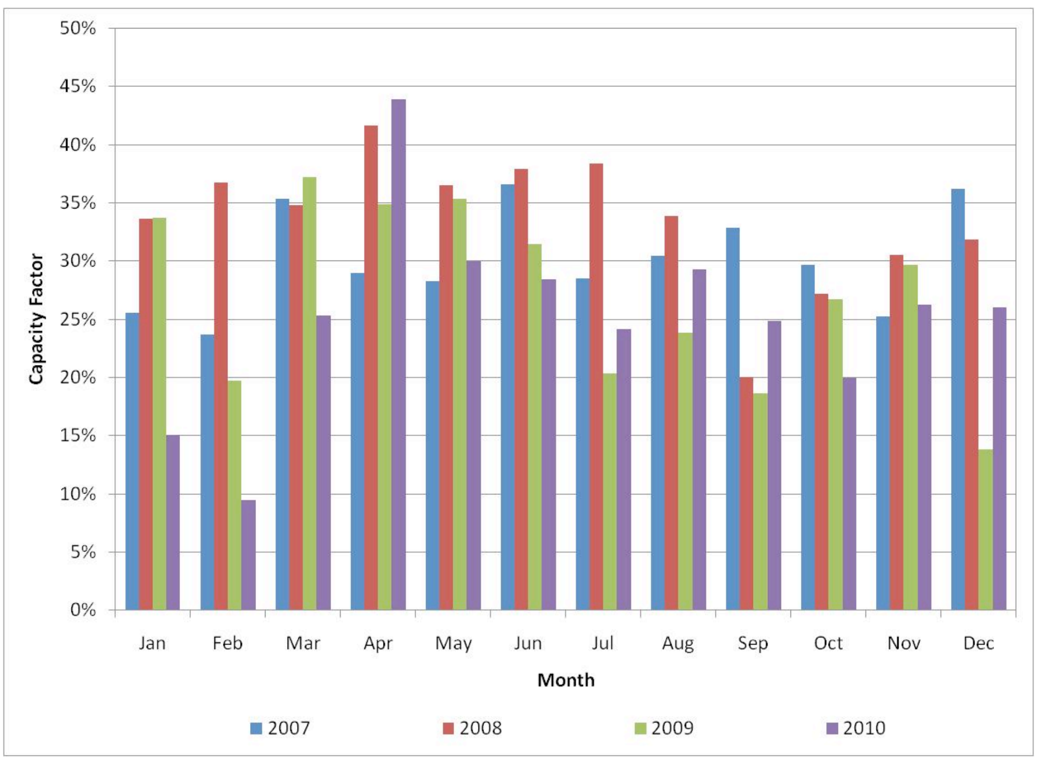


Figure G-4 shows the variability in monthly capacity factors at the Wild Horse wind project. The monthly generation varies from month to month within each year and it can also vary significantly for a given month between years. February is a good example with a range of capacity factors from below 10 percent to above 35 percent. Wind generation tends to peak in March and April and typically exceeds the annual capacity factor through the spring and into early summer. 2010 was a notable year because PSE experienced its worst month (February) and best month (April) on record. Annual capacity factors for 2007, 2008, 2009, and 2010 were 30 percent, 34 percent, 27 percent, and 25 percent, respectively.

Figure G-4
Wild Horse Average Monthly Capacity Factor by Year



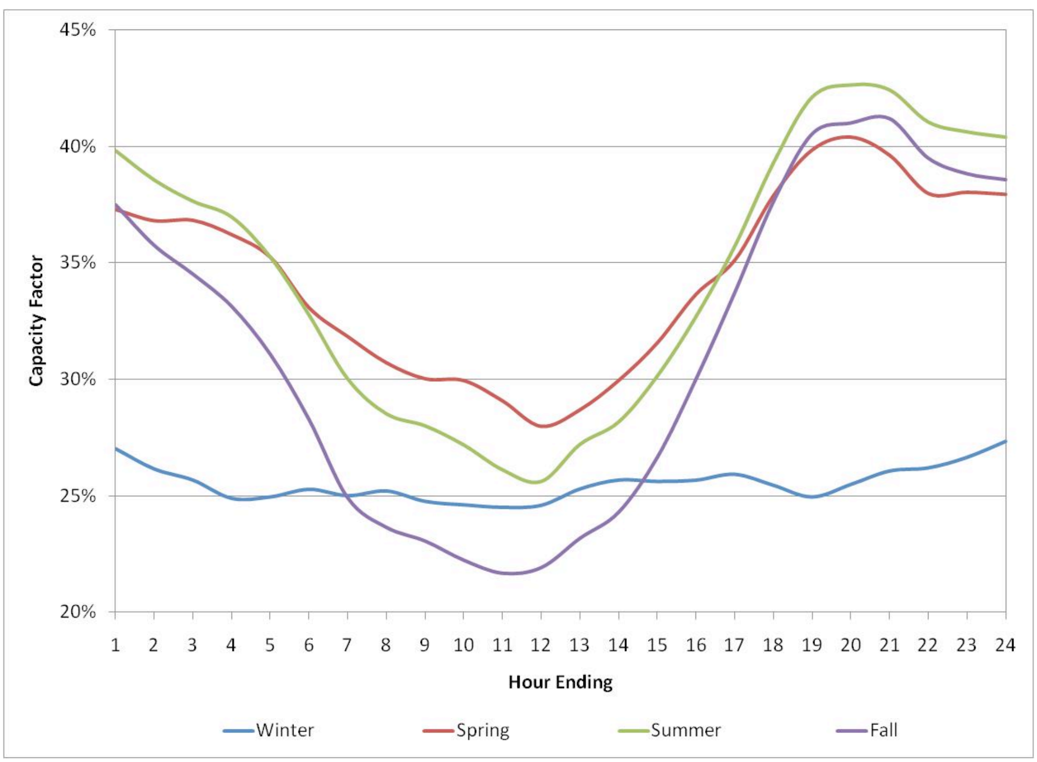
Wind also varies by time of day and between seasons. For the purpose of this analysis, the year was divided into four seasons as defined in Figure G-5.

Figure G-5
Seasonal Break Down

Season	Months
Winter	December, January, February
Spring	March, April, May
Summer	June, July, August
Fall	September, October, November

The four-year average hourly capacity factor for the Wild Horse wind project is shown in Figure G-6. During the spring, summer and fall, a very prominent shape emerges where wind output is strongest in the early evening hours and drops off significantly in the morning hours. The winter capacity factors are generally flat across the day.

Figure G-6
Average Hourly Wild Horse Capacity Factor



Ramping of Wind Output

While there is no one consistent definition of a wind ramp, it is important to study the output across various time horizons as they all have different impacts on system operation. To date, the PSE system has successfully managed all observed ramping events.

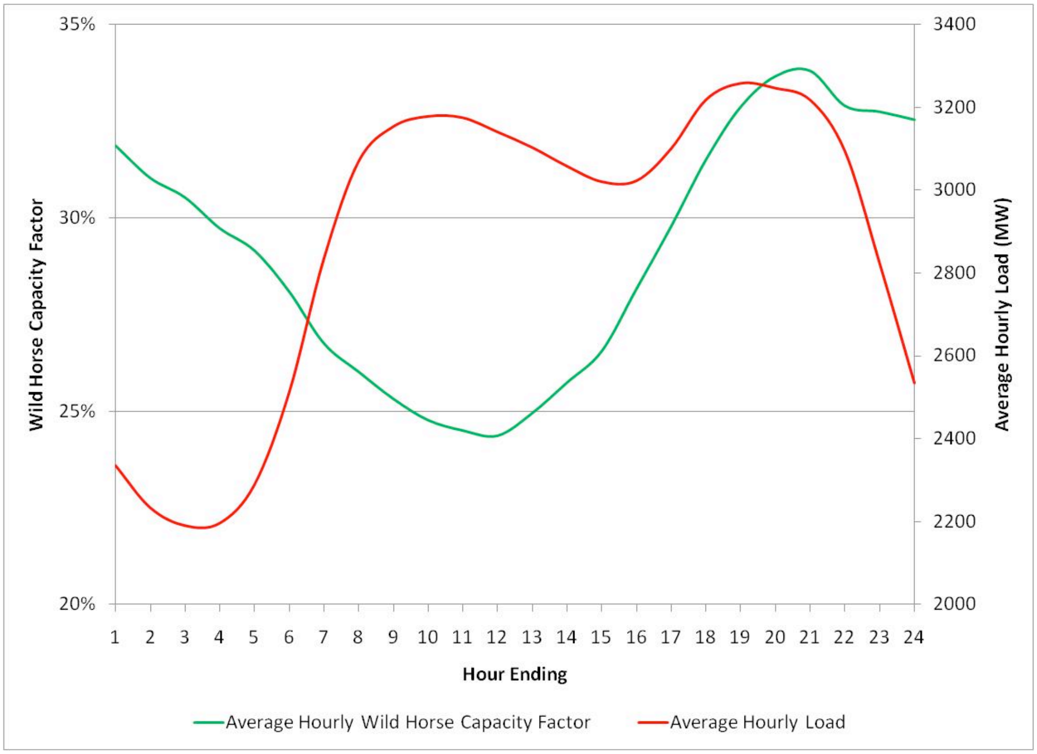
Large wind output changes over minute-to-minute intervals are rare at both Hopkins Ridge and Wild Horse wind projects. Over a 10-minute horizon, the standard deviation at both projects is approximately 4 percent of plant capacity. Over a thirty-minute window, about 1 percent of observed output changes are greater than 50 MW for Hopkins Ridge and 75 MW for Wild Horse, or approximately 30 percent of plant capacity. Across the hour, the 1 percent extreme ramp threshold is roughly 50 percent of installed capacity at each wind project.

Another approach to quantify ramp events, which has been used by some organizations in the Pacific Northwest, is to count wind output changes of 20 percent or more of capacity, over a 30-minute window. This method reveals that low capacity factor months generally have fewer ramping events relative to other months while the consistently high capacity factor months have the most ramp occurrences, and is true at both farms.

Wind Interaction with Load

The wind and load relationship is important because the direction and timing of wind ramp events and forecast deviations can have positive or negative impacts on the ability to match power generation to consumer demand. For example, as shown in Figure G-7, PSE load generally peaks twice every day, once in the morning and the second time in the later afternoon/early evening. This dual peaking phenomenon is stronger in the winter compared to summer. Wind generation typically peaks in the late evening to early morning and then ramps down during the morning load peak.

Figure G-7
Average Hourly Net Capacity Factor and Load



Net Load

Net load is equal to load minus wind generation and is a critical component to accurately plan for increasing wind penetration. When assessing system requirements, net load is analyzed rather than wind or load alone. The overall magnitude of the wind or load alone is less important than the magnitude and direction of the change in wind and load relative to each other.

Diversity of Wind

Diversity of wind generation output can play a role in system operations but at this time does not drive the wind project acquisition process. There is noticeable wind diversity between the Wild Horse wind project and the Hopkins Ridge wind project, especially over shorter time horizons. The diversity between the two projects is generally not due to one farm decreasing in wind output while the other ramps up, but rather when one farm experiences a large change in output the other farm experiences little to no output change.

Similar diversity effects are found when comparing load and wind volatility. This effect varies throughout the year. In winter months, there is greater diversity. However, the winter months are when load is also most volatile compared to the least volatile summer months. The relative impact of wind on net load volatility declines at longer time horizons due to the changes in load volatility being much greater than the changes in wind volatility. However while the changes in load are much larger over one hour time intervals than those of wind, the load changes are more predictable as well.

4. Integration of Hopkins Ridge Wind Project

As already mentioned, PSE's 157 MW Hopkins Ridge wind project is interconnected to BPA's BA and integrated into BPA's system. The hourly scheduled amount of power is delivered to the PSE system. Wind is scheduled 30 minutes prior to the start of the hour and the schedule is automatically sent to BPA. The wind schedule is developed every hour using the most up-to-date information from a combination of actual real-time observations and vendor-provided forecast models. The forecast model employs publicly available weather forecasts, advanced statistical algorithms, numerical weather prediction models and a self-learning artificial intelligence logic.

BPA's integration services are two-fold. One service -- generation imbalance -- captures the after-the-fact difference between the hourly average generation that was scheduled, versus what was actually produced. The second service -- wind integration -- manages the second-to-second, minute-to-minute variability in wind generation by providing regulation and wind generation following. BPA's current wind integration rate is $1.29 per KW-month or $5.97 per MWh assuming a 30 percent capacity factor. BPA is currently in the process of the 2012 BPA Power and Transmission Rate Cases, which will set a new wind integration rate effective October 1, 2011.

5. Ancillary Services

Overview

North American Electric Reliability Corporation (NERC) defines ancillary services as "those services that are necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the Transmission Service Provider's transmission system in accordance with good utility practice"[1]. This section focuses on two ancillary services that fall under this broad NERC ancillary service definition: regulating reserves and net load following.

Regulating Reserves

Within the regulation time frame, which corrects for the moment-to-moment fluctuations in wind and load, wind is relatively more volatile than load. However, since the wind penetration in PSE's system is relatively low in comparison with load, the current amount of regulating reserves is driven primarily by load volatility. As wind penetration levels increase, wind volatility may become more influential within the regulation time frame.

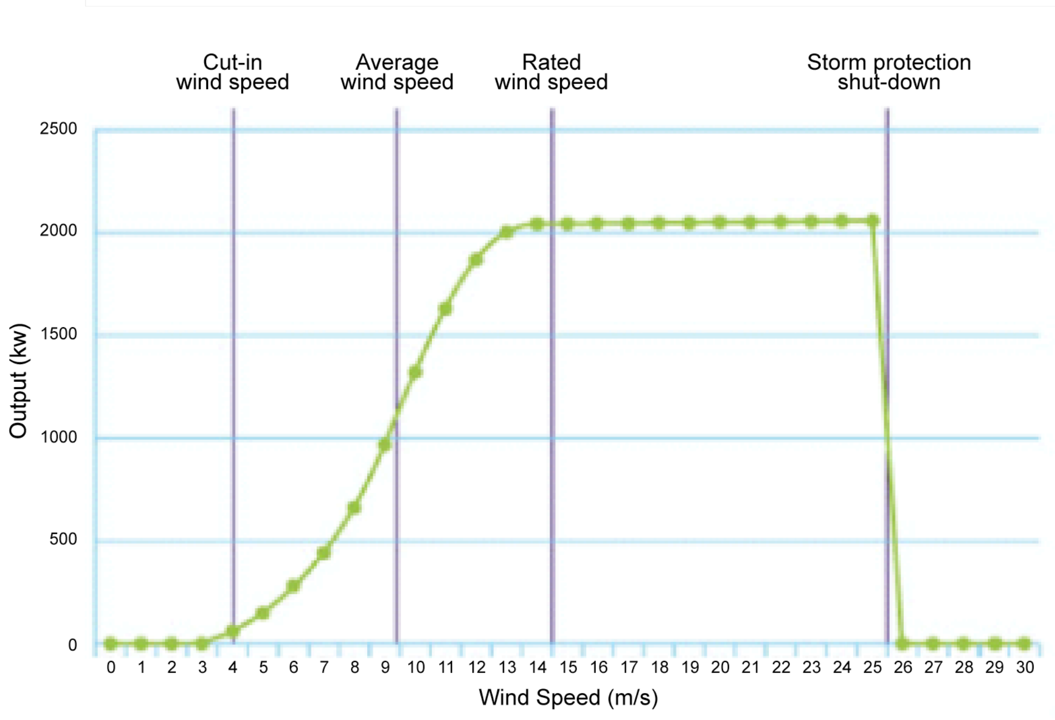
The regulating reserves needed to manage the wind output from the Wild Horse wind project alone is approximately 30 percent of the regulating capacity needed to manage load alone. When the wind output and load are netted together, the incremental increase in regulation capacity due to wind is only marginally higher (4.8 percent) than load alone.

As already mentioned, regulating reserve requirements are driven by load and wind variability. For wind alone, the variability in the wind output is dependent on the wind speed. The power curve of a generic wind turbine, shown in Figure G-8, illustrates the relationship between wind speed and the associated power output. The graphs shows that changes in wind output, when the wind speed is low or high, are relatively small in comparison to the changes in output that can be observed when the wind speed is the middle of the range, between 5 m/s and 13 m/s. The distinction of where on the power curve a turbine is currently generating is important because, at the regulation timeframe of moment-to-moment, wind speeds can only change so much, placing the emphasis on how a change in wind speed translates to a change in power output.

[1] http://www.nerc.com/docs/standards/rs/Glossary_of_Terms_2010April20.pdf

Figure G-8

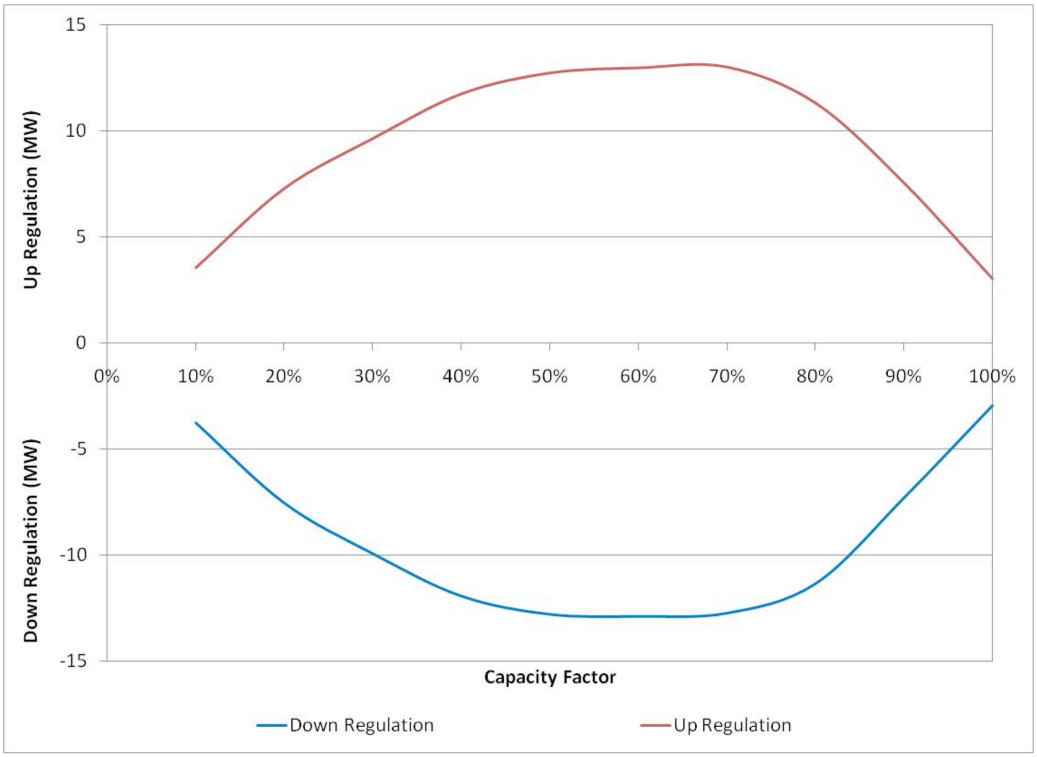
Generic Wind Turbine Power Curve



As per the wind speed and wind output relationship, the regulation requirements follow the same pattern. Figure G-9 confirms that the relative amount of up regulation (to balance decreases in wind output) and down regulation (to balance increases in wind output) needed to balance Wild Horse wind output is small when the percentage of output to nameplate capacity, or capacity factor, is low or very high - but the need is larger when the capacity factor is between 40 percent and 70 percent. Although the up and down regulation appear similar in shape and magnitude, they are not identical.

Figure G-9

Wild Horse Regulation Requirements by Capacity Factor

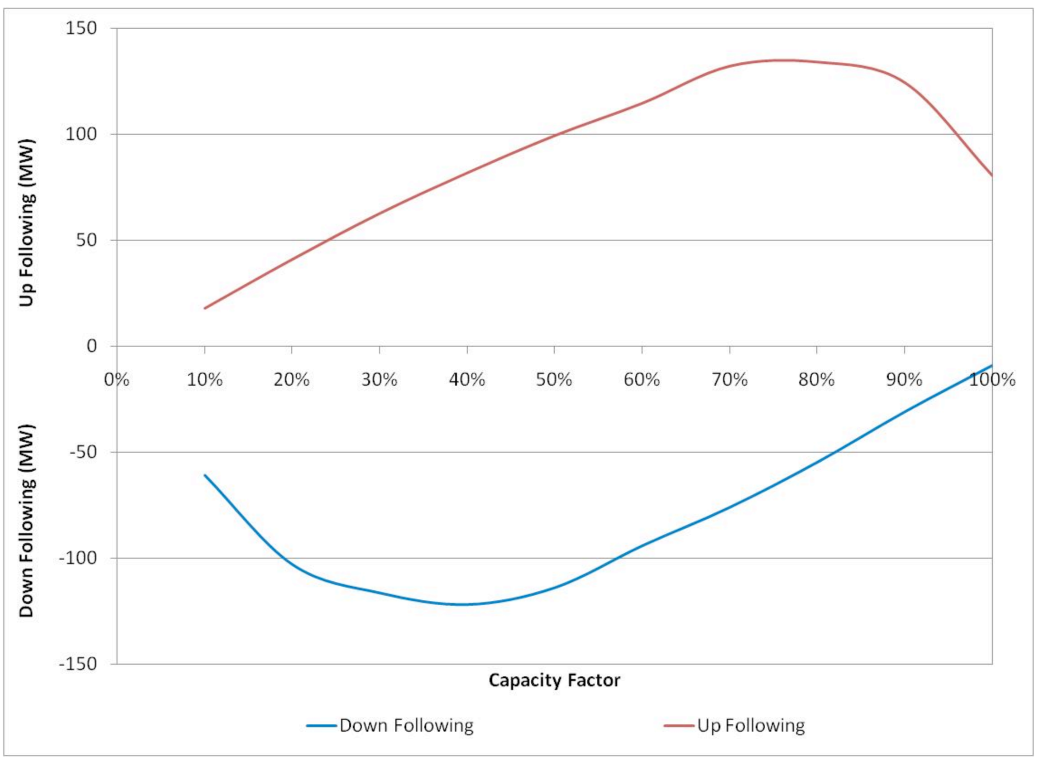


Net Load Following

Load following is not specifically defined by NERC, but it is understood to correct for differences across 10-minutes and up to the next hour, between scheduling windows. The assessments of following requirements focus on net load following or the net impact of load and wind. Similar to regulation, the level of wind output also disproportionately impacts the net load following requirements.

Figure G-10 provides an example of the up and down following requirements for Wild Horse wind generation alone. The up and down following requirements are not symmetrical. Up following is needed when the wind output decreases and therefore, at higher wind output levels, there is the potential for a substantial decrease in output over the course of an hour, requiring other resources to provide larger quantities of up following reserves. The reverse occurs for down following. For example, when a wind project is generating at its maximum output, only up following is needed because the generation can only go down while at mid-generation the output could potentially increase or decrease, requiring similar amounts of both up and down following reserves.

Figure G-10
Wild Horse Up and Down Following by Capacity Factor



6. *Managing Ancillary Services*

Existing Ancillary Services

If actual real-time generation output diverges from the hourly scheduled wind output, as shown in Figure G-2, the operator must rebalance the system by increasing or decreasing generation from Mid-Columbia and other generating assets within our system. The instantaneous fluctuations are generally mitigated by Mid-Columbia hydro generation, which is on automatic generation control (AGC) and can respond instantaneously. Large, unanticipated ramping events must be managed within the hour with a combination of AGC and dispatcher actions. Net load following corrects for differences over longer time increments of 10 to 50 minutes between hourly scheduling adjustments. Wind variability and uncertainty drive PSE's need to carry additional reserves for the purpose of balancing net load.

For most of the calendar year, PSE's share of Mid-Columbia hydro generation is sufficient to manage the instantaneous load and wind variability and any within-hour deviations from their respective schedules. During the spring runoff period, however, when the Columbia River flows are high, the Mid-Columbia hydro system has to be managed to stay within the legal Total Dissolved Gas (TDG) limits by minimizing spill. Mid-Columbia flexibility is limited between available capacity and the minimum generation limit that does not violate the TDG limits.

During times when the Mid-Columbia hydro system does not provide the necessary flexibility to manage net load, PSE uses its thermal resources and market transactions to balance the system. During spring 2008, PSE experienced insufficient Mid-Columbia hydro flexibility and had to use its thermal resources and market transactions to support system operations. The thermal resources were dispatched and operated at minimum, mid-point and base load to provide the flexibility to either increase or decrease generation depending on the nature of net load deviations. For this period, Mid-Columbia hydro supported all of its regulating reserve requirements but the following requirements were supported less than 20 percent of the time. Typically, Mid-Columbia hydro supports the majority of the regulation and following requirements.

PSE also has had limited success procuring ancillary products in the forward market. During the spring 2008 high runoff event, PSE secured 50 MW of spinning reserve capacity for a six-week period during the peak of the spring runoff. Long-term capacity products help balance the PSE portfolio and are considered a viable option for wind integration.

Future Ancillary Services

Due to expiring Mid-Columbia hydro generation contracts, by the year 2020 PSE's share of the Mid-Columbia hydro, including Upper Baker hydro, is expected to be 795 MW, or 261 MW less than today's capacity. This loss of hydroelectric generating capacity may require PSE to have other assets available to provide ancillary services.

All of the regulating reserves are currently provided by the AGC from PSE's share of Mid-Columbia hydro generation. Even as our contractual rights of the Mid-Columbia hydro projects change and PSE's total capacity decreases through to 2020, we will be able to continue to reliably satisfy the regulating reserve requirements for future portfolio needs and wind penetration changes. In actual operations, we may decide to manage the system differently and utilize different sources of AGC.

A likely combination of combined cycle (CCCT) and simple cycle (CT) natural gas turbines may be needed to provide net load following during times of high demand or flow-constrained Mid-Columbia hydro conditions. In 2020, the 2011 IRP Base Case scenario estimates that PSE's gas-fired thermal fleet will consist of the same four CCCT units currently in operation, while all but two CT units will be replaced. PSE's ability to provide the required ancillary services to manage net load following and maintain system reliability will undoubtedly require a more integrated operational strategy in which some of the ancillary service capacity currently being provided by the Mid-Columbia hydro will be shifted to PSE's thermal units as well as available market alternatives. Should we determine that long-term power purchase agreements are the least cost option to meet load, other options of providing ancillary services may need to be identified.

Modeling Future Ancillary Service Capability

This assessment of PSE's ability to provide future ancillary services focuses on net load following requirements. Regulating reserve capacity is provided by Mid-Columbia hydro and effectively reduces the Mid-Columbia hydro's capability for net load following.

To determine the future impacts of reduced Mid-Columbia hydro capacity and a different thermal resource portfolio to meet ancillary service requirements, the Aurora model was used to set the dispatch of hydro and thermal units based on the 2020 Base Scenario. Aurora sets the hydro generation and it also provides baseline operating characteristics for the thermal fleet in terms of operating hours, starts, and total generation. The Ancillary Service Model (ASM) evaluates the PSE system's capability to meet net load following. The ASM utilizes the dispatch from Aurora as inputs and adjusts the generation of units capable of providing net load following: Mid-Columbia hydro, Upper Baker hydro, CCCT and CT thermal units.

Net load following is entered into the ASM as an hourly input which represents the hourly capacity required to manage the uncertainty in load and wind. Most production cost models may not account for reserves and ancillary service requirements, so treating these requirements in another model as a secondary step is a reasonable approach and may significantly change the operating behavior of some resources. The ASM takes a least-cost approach to meeting net load following by utilizing hydro resources first and then the thermal resources. PSE resources are considered sufficiently flexible if the available capacity meets all of the net load following requirements at the 95 percent confidence interval. The model also calculates the changes in output since all resources start from economic dispatch and are then adjusted to a less optimal or efficient generation to meet the net load following.

Model Assumptions

Below is a list of the major modeling assumptions driving the ASM to meet net load following using the capabilities of the hydro and thermal resources:

- 795 MW of hydro capacity;
- Resource portfolio includes four CCCT and eight CT resources;
- Various wind penetration levels were analyzed: 273 MW of Wild Horse wind capacity, 430 MW of total capacity from Wild Horse and Hopkins Ridge and 773 MW of total capacity from Wild Horse, Hopkins Ridge and LSRI; and
- Hourly electric and gas price data were used in conjunction with net load following derived from historical deviations in hour-ahead forecasts.

The general modeling approach follows these steps:

- Net load following is provided first by reshaping the hourly hydro generation.
- If additional net load following is needed and combined cycle units are economically dispatched, their output is adjusted to hold back net load following capacity.
- Finally, if additional net load following is still required, the output from simple cycle plants is adjusted if economically dispatched, or they started to meet the remainder of the following requirement.

Summary of Results

It is important to note that this analysis utilizes only one of many possible future resource portfolios. The assumptions made represent the best estimate of the likely resources available to the utility in the year 2020 capable of providing ancillary services. However, PSE's acquisition strategy may result in a different portfolio, ancillary services markets could develop, or PSE's anticipated balancing area responsibility may change.

Figure G-11 provides several statistics on how hourly net load following is being met by PSE's resource portfolio. Results for the following three wind scenarios are provided:

1. 273 MW Wild Horse wind project (identified as WH);
2. 430 MW of Wild Horse and Hopkins Ridge installed capacity (identified as WH+HR);
3. 773 MW of Wild Horse, Hopkins Ridge and LSRI installed capacity (identified as WH+HR+LSR).

Most of the up and down following will be provided by the Mid-Columbia hydro, as is currently the case. However, as wind penetration increases, the thermal resources will be used increasingly more to provide net load following. All of the net load following requirements are met in the three scenarios shown in Figure G-11. In the WH+HR+LSRI scenario, as much as 20 percent of the up following and 30 percent of the down following may be provided the thermal resources.

In the WH scenario, the results may not exactly reflect historical operating statistics because the dispatchers and operators may take a different approach to managing net load following. However, the incremental impact of additional wind may be indicative of what may occur in reality and may provide useful information for system operators and planners.

Figure G-11
Ancillary Service Modeling Results

Wind Scenario	% Up Followin g met by Hydro	% Down Following met by Hydro	% Up Following met by Thermals	% Down Following met by Thermals	Average Annual Starts per CT	Average Additional CT Starts per Month	Incremental Increase in CT Starts per Month per CT
WH	91%	88%	9%	12%	139	12	12
WH + HR	90%	86%	10%	14%	176	15	3
WH + HR + LSR	80%	70%	20%	30%	234	20	5

To provided hour-ahead ancillary services for load net Wild Horse alone, each of the eight CTs would be called upon to start 12 additional times per month. The annual number of starts per CT per month will vary seasonally. The ancillary service requirements for incremental wind are not additive because of wind diversity. When the Wild Horse and Hopkins Ridge wind projects are modeled together, the percent change in CT starts above economic dispatch only increases 27 percent above starts required to support the Wild Horse project alone, while wind capacity increases over 58 percent. The percent change in CT starts needed to balance all three wind plants only increases 33 percent while wind capacity increases 73 percent.

Figure G-12 shows the impact hourly net load following has on CCCT and CT generation. The annual amount of CCCT generation decreases when providing net load following. This is a function of how the model utilizes CCCTs to provide net load following. A CCCT unit can only provide following if it is already online and running. If a unit is running based on economic dispatch, then most likely it is running at base load, which means that the plant is already providing down following. If, however, up following is needed, the unit must reduce its generation to have sufficient capacity available to provide up following. This operational assumption results in a very small decrease in CCCT generation initially and a slight increase in generation to support the three wind projects. On the other hand, results show a large change in CT generation. The 12 to 20 additional CT starts described above result in increases in CT generation anywhere from 42 percent to 180 percent.

Figure G-12

Percent Change in Annual Generation by Thermal Resource

Wind Scenario	% Change in CCCT Generation	% Change in CT Generation
WH	-0.15%	42%
WH + HR	-0.26%	52%
WH + HR + LSR	0.21%	180%

Based on these results, PSE is confident that the 2020 anticipated resource stack is capable of meeting the ancillary service requirements for wind and load projections in the year 2020. While the exact number and capacity of wind plants within PSE's BA is unknown, the above results indicate that the system may have enough ancillary service benefits to support the requirements for the wind shown here. In actual operations, PSE may decide to manage the system differently and as a result will use different resources and process to provide the ancillary services.