# Survey of Variable Generation Forecasting in the West

## August 2011 — June 2012

K. Porter and J. Rogers
*Exeter Associates, Inc.*
*Columbia, Maryland*

**NREL Technical Monitor: Dr. Kirsten Orwig**

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# Acknowledgements

# Nomenclature

| | |
|---|---|
| AESO | Alberta Electric System Operator |
| APS | Arizona Public Service |
| BA | Balancing Authorities |
| BPA | Bonneville Power Administration |
| CAISO | California Independent System Operator |
| COP | Current Operating Plans |
| CP | commercial pricing |
| DIR | Dispatchable Intermittent Resource |
| DOE | U.S. Department of Energy |
| ERCOT | Electric Reliability Council of Texas |
| FERC | Federal Energy Regulatory Commission |
| LMP | Location marginal price |
| MAE | Mean Absolute Error |
| MAPE | Mean Absolute Percentage Error |
| met | meteorological |
| MISO | Midwest Independent System Operation |
| MW | megawatts |
| NERC | North American Electric Reliability Corporation |
| NSRS | Non-spinning Reserve Service |
| NWP | Numerical Weather Prediction |
| PIRP | Participating Intermittent Resource Program |
| PSCO | Public Service of Colorado |
| PURPA | Public Utility Regulatory Policies Act |
| QSE | Qualified Scheduling Entities |
| RMSE | Root Mean Square Error |
| RTO | Regional Transmission Organization |
| SCE | Southern California Edison |
| SCED | Security Constrained Economic Dispatch |
| SMUD | Sacramento Municipal Utility District |
| SPS | Southwestern Public Service |
| SPSC | State Provincial Steering Committee |
| STWPF | Short-Term Wind Power Forecast |
| TRE | Texas Reliability Entity |
| Turlock | Turlock Irrigation District |
| VGS | Variable Generation Subcommittee |
| WECC | Western Electricity Coordinating Council |
| WEPROG | Weather and Wind Energy PROGnosis |
| WGR | wind-powered generating resource |
| WIEB | Western Interstate Energy Board |

# TABLE OF CONTENTS

**PAGE**

# LIST OF FIGURES

# LIST OF TABLES

# Executive Summary

This report surveyed Western Interconnection Balancing Authorities regarding their implementation of variable generation forecasting, the lessons learned to date, and recommendations they would offer to other Balancing Authorities who are considering variable generation forecasting.  Our survey found that variable generation forecasting is at an early implementation stage in the West. Eight of the eleven Balancing Authorities interviewed began forecasting in 2008 or later.  It also appears that less than one-half of the Balancing Authorities in the West are currently utilizing variable generation forecasting, suggesting that more Balancing Authorities in the West will engage in variable generation forecasting should more variable generation capacity be added.

Several large-scale variable generation integration studies have determined that incorporating today's state-of-the-art variable generation forecasts into advance scheduling (e.g., day-ahead) and generation plant dispatching can reduce total system operating costs through decreased fuel consumption, operation and maintenance costs, and more efficient plant dispatch overall.  Most of the Balancing Authorities interviewed for this report use variable generation forecasts for intra-day unit commitment, not for forward unit commitment.  By comparison, Electric Reliability Council of Texas (ERCOT) and the Midwest Independent System Operator (MISO) use variable generation forecasts for determining their forward unit commitment schedules.  Transitioning to incorporating variable generation forecasts into forward unit commitment schedules will help to make generation scheduling decisions more efficient.

There is no agreement among Balancing Authorities in the West on what defines or what comprises certain types of forecasts, such as short-term or medium-term forecasts.  Also, only a small number of Balancing Authorities interviewed for this report are utilizing ramp forecasts.  Most of the Balancing Authorities interviewed stated that it takes time to implement a variable generation forecasting system and recommended that other Balancing Authorities should start early with variable generation forecasting.  In addition, few of the Balancing Authorities interviewed for this report have conducted detailed cost-benefit studies of variable generation forecasting, and those who did employed different methodologies.  Some questioned the need for such a study, since the costs of forecasting are small compared to the benefits, and variable generation forecasting has to be seen as a necessity with higher levels of variable generation.

When variable generation forecasting in the Western Interconnection was compared with forecasting in ERCOT and in MISO, the most significant difference was the larger size of the ERCOT and MISO balancing areas, as compared to other Balancing Authorities in the West.  This suggests that variable generation forecasting accuracy in the West could improve if initiatives are adopted, such as some or all of the Efficient Dispatch Toolkit, for coordination across Balancing Authorities.  ERCOT and MISO also have other mechanisms such as sub-hourly scheduling, liquid day-ahead and real-time energy markets, pricing of transmission congestion, and ancillary service markets, instead of the tariff rates used by most Balancing Authorities in the West.  It also suggests that while variable generation forecasting is vital, other mechanisms for integrating variable energy generation will be needed should increased deployment of variable generation continue in the West.

# 1 Introduction on Variable Generation Forecasting

It is widely acknowledged that increased use of variable generation forecasting will be necessary to maintain grid reliability as more variable generation is added. North American Electric Reliability Corporation (NERC) stated that "enhanced measurement and forecasting of variable generation output is needed to ensure bulk power system reliability," and that wind forecasting "must be incorporated into real-time operating practices as well as day-to-day operational planning" (NERC 2009). A recent survey of grid operators world-wide found near-unanimous agreement that integrating a significant amount of wind will largely depend on the accuracy of the wind power forecast (Jones 2011).

Variable generation forecasts are prepared with both physics-based models, known as Numerical Weather Prediction (NWP) models, and statistical models. The NWP models are a simulation of the atmosphere and the physical processes that affect the atmosphere. Statistical models are based on the quantitative relationships between the input data (usually historical wind or solar production) and output data (the forecast). A typical approach for wind forecasting companies is to take values from NWP models and historical production data from the wind plants to forecast variables, such as wind speed at hub height, expected wind output, and so on. The statistical models can account for local terrain and help translate the output of NWP models by showing relationships between past weather events and wind production.

Forecasting companies may also prepare an ensemble of individual forecasts by varying the input data or model parameters. A type of ensemble forecast is one in which the forecasting customer uses multiple forecasting companies and then evaluates and uses the multiple forecasts in some fashion. Variable generation forecasts may also include a confidence interval in the forecast, or probabilistic forecasts that indicate multiple probabilities of forecasted variable generation production. Finally, some forecasting companies are preparing "ramp" forecasts for variable generation that predict low-probability, but high impact events, of large increases or decreases in variable generation (NERC 2010).

# 2 Project Background

In 2010, the U.S. Department of Energy (DOE) awarded a grant under the American Recovery and Reinvestment Act of 2009 to the Western Governors' Association. It included work to enhance the states' capacity to effectively participate in interconnection-wide transmission planning, already underway under a companion DOE grant to the Western Electricity Coordinating Council (WECC). These state participation activities under the DOE grant are occurring through the State Provincial Steering Committee (SPSC).

One of three goals that the SPSC named was to identify actions that lower the cost of integrating variable energy resources into the grid. Variable generation forecasting was identified as a key factor for integrating variable energy resources into the grid. The SPSC requested assistance from the National Renewable Energy Laboratory and the DOE Office of Electricity Delivery and Energy Reliability to survey wind and solar forecasting practices in the Western Interconnection. Specifically, the SPSC requested telephone interviews that expanded on an earlier written survey of Balancing Authorities (BA) on variable generation forecasting conducted by WECC's

Variable Generation Subcommittee (VGS). The VGS sent a survey to 37 Balancing Authorities in WECC in May 2011, and received responses from 14.  The two-page survey asked:

- Whether the balancing authority was engaged in variable generation forecasting

- How the forecast was used

- What data was collected

- Whether third party vendors were engaged

- How far in advance the forecast was due

- What performance metrics are used to evaluate forecast error

- The amount of installed wind and solar capacity in the balancing authority

- Current load in the balancing authority

Of the 14 survey respondents, 7 responded that they forecast wind and/or solar generation, and 12 said they would be willing to participate in a phone interview.

Phone interviews were conducted with Balancing Authorities that are actively engaged in variable generation forecasting.  In addition to the phone interviews, the SPSC was interested in comparing the state of variable generation forecasting in the Western Interconnection with Balancing Authorities employing "best practices" in variable generation forecasting.  A draft survey was prepared and revised in consultation with NREL and the Western Interstate Energy Board (WIEB).  The original and revised survey questions are included in Appendices B and C.

After reviewing the results of the VGS variable generation forecasting survey and based on the authors' knowledge of those BAs that are utilizing variable generation forecasts, 11 BAs were selected for interviews (see Table 1 for a listing of the BAs surveyed with load, wind capacity, and solar capacity data; see Figure 1 for geographical location of the BAs surveyed).[1] Collectively, the 11 Balancing Authorities interviewed have 10,773 megawatts (MW) of wind in their balancing area, or more than 84% of the wind capacity in the Western Interconnection.[2] We caution that not all 10,773 MW of wind are forecast – some wind projects are not forecast because of their small size, grandfathering arrangements, or because the wind plants have been in operation for some time and the cost to install the needed telemetry or communication equipment is considered prohibitive.[3] We also note that while variable generation forecasting appears to cover much of the current wind capacity in the West, less than half of the balancing areas in the West are actively engaged in variable generation forecasting.  Therefore, as more wind or solar capacity is developed in the future, more Balancing Authorities in the West will likely engage in

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[1] Southern California Edison (SCE) is not a balancing authority per se—the CAISO is the balancing authority for most of California. However, SCE was one of the first, if not the first, electric utility in the United States to employ wind forecasting, and for that reason, SCE was chosen to be interviewed.

[2] Wind capacity data for WECC was derived from the North American Electric Reliability Corporation.  *2011 Long-Term Reliability Assessment*, November 2011.  http://www.nerc.com/files/2011LTRA_Final.pdf.

[3] Xcel Energy, for example, said it received data on 84% of wind capacity and the maximum data it could receive is 91%. The remaining 9% consists of small projects below 10 MW or grandfathered projects that were built before 2003 and do not have compatible data communication systems with Xcel Energy.

variable generation forecasting.  The Balancing Authorities also have nearly 800 MW of solar photovoltaics and concentrating solar power capacity installed, or about 22% of total grid-connected solar capacity in the United States.

**Table 1.  Balancing Authorities Interviewed for this Report**

| Balancing Authority | Load (MW) | Wind Capacity in Balancing Authority (MW) | Solar Capacity in Balancing Authority (MW) |
|---|---|---|---|
| Alberta Electric System Operator (AESO) | 8,400 | 865 | 0 |
| Arizona Public Service (APS) | 2,939-4,650 | 205[1] | 61.9 |
| Bonneville Power Administration (BPA) | 6,000 | 3,788 | <1 |
| California Independent System Operator (CAISO) | 24,315 to 30,611[2] | 3,598 | 498 |
| Glacier Wind | NA | 210 | 0 |
| Idaho Power Co. | 1,800 | 485 | 0 |
| Northwestern Energy | 1,805 | 138.59 | 0 |
| Sacramento Municipal Utility District (SMUD) | 3,280 | 0 | 35 |
| Southern California Edison (SCE) | 23,303[3] | [4] | [4] |
| Turlock Irrigation District (Turlock) | 245-336 | 0[5] | 2 |
| Xcel Energy (PSCO)[6] | 3,878-4,340 | 1,484 | 200 |
| TOTAL | 75,965-84,525 | 10,773.59 | 797.9 |

[1]  190 MW is dynamically transferred from Public Service of New Mexico; another 15 MW is transferred out of APS to Salt River Project
[2]  Range for 2011 monthly averages
[3]  Represents all time peak
[4]  SCE has 2,057 MW of wind capacity and 383 MW of solar capacity, which is included in the wind and solar numbers for the California Independent System Operator.
[5]  Owns a wind project in Bonneville Power Administration's service area
[6]  Data is for Public Service of Colorado's service territory.

*Southern California Edison is not a balancing authority
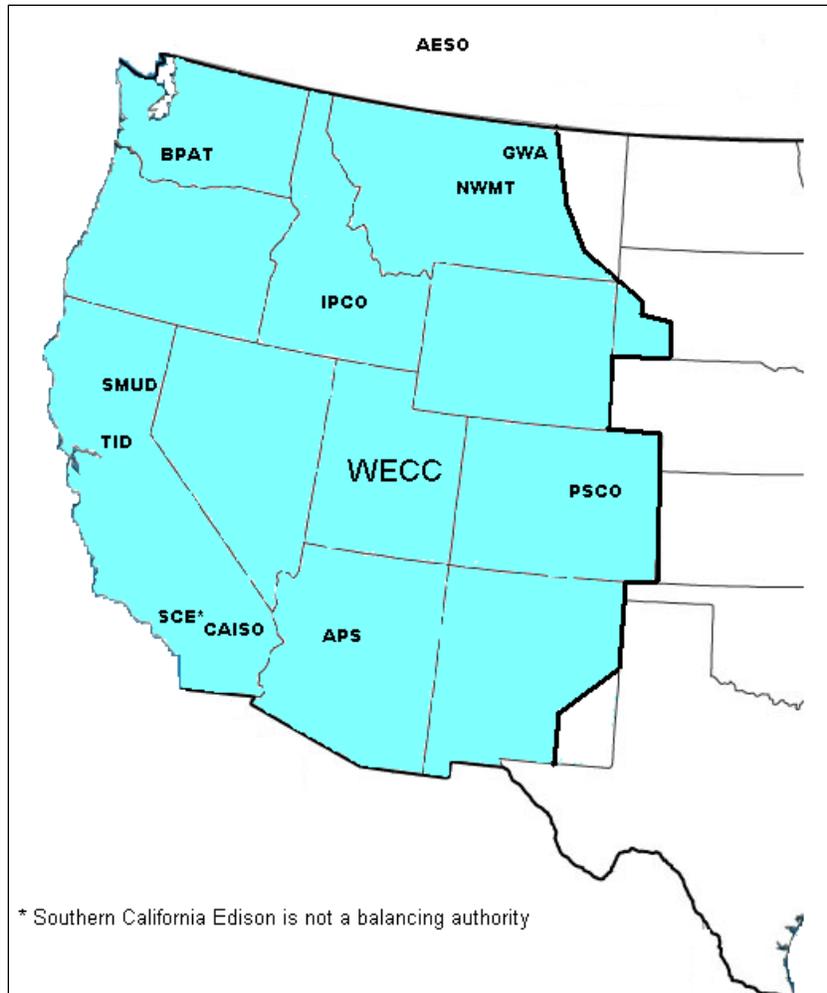
**Figure 1. Location of Balancing Authorities Interviewed for this Report**

The next section of this report summarizes the responses to the survey. After that, the status of wind forecasting in the West will be compared with Balancing Authorities considered to employ "best practice" variable generation forecasting in the United States. A summary closes the report.

# 3   Summary of Responses to Phone Interviews

## 3.1   Initiation of Forecasting

The Balancing Authorities profiled began forecasting variable generation at different times. Four of them began forecasting in 2005 or earlier (CAISO, Northwestern Energy, Xcel Energy and SCE), and the remaining seven began in 2008 or later; two began 2011, as depicted in Table 2.

**Table 2.  Year Balancing Authority Began Variable Generation Forecasting**

| Balancing Authority | Year Forecasting Began |
|---|---|
| AESO | 2010 |
| APS | 2008 |
| BPA | 2009 |
| CAISO | 2004 |
| Idaho Power | 2011 |
| Glacier Wind | 2009 |
| Northwestern Energy | 2005 |
| SMUD | 2011* |
| SCE | 2000 |
| Turlock | 2009 |
| Xcel Energy | 2005 |

* For solar forecasting only.  SMUD receives wind forecasts through CAISO's
Participating Intermittent Resources Program.

As indicated in Table 3, all of the Balancing Authorities interviewed forecast wind except for the Sacramento Municipal Utility District (SMUD), which participates in the CAISO's variable generation forecasting program known as the Participating Intermittent Resource Program (PIRP) for wind.  SMUD has also just recently begun solar forecasting.  The only other organizations conducting solar forecasts are the CAISO, SCE, and Xcel Energy.[4]  The Balancing Authorities who do not forecast for solar explained that they do not have enough solar capacity to justify solar forecasting, although APS indicated they may conduct solar forecasting in the future.

**Table 3.  Balancing Authorities Surveyed that Utilize Wind or Solar Forecasting**

| Balancing Authority | Wind Forecast | Solar Forecast |
|---|---|---|
| AESO | X | |
| APS | X | |
| BPA | X | |
| CAISO | X | X |
| Glacier Wind | X | |
| Idaho Power | X | |
| Northwestern Energy | X | |
| SMUD | * | X |
| SCE | X* | X |
| Turlock | X | |
| Xcel Energy | X | X |

* Participant in CAISO's PIRP program.

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[4] SCE also participates in PIRP.

## 3.2  Timeframes for Forecasts

Table 4 provides a high-level overview of each respondent's forecasting practices, divided into short-term, medium-term, long-term, and ramp forecasts.  Although nearly every company has short-term and medium-term forecasts, there is diversity among companies in how often forecasts are prepared and the frequency of their updates.

- Nearly all of the Balancing Authorities interviewed have hourly variable generation forecasts that are classified here as short-term forecasts.

- How often short-term forecasts are updated varies, from every 10 to 15 minutes to hourly.

- The short-term forecasts also vary in how far into the future conditions are forecast, from the next hour to one week-ahead (168 hours).

- Similar variation was observed in the medium-term forecasts.

- Five Balancing Authorities (Glacier, APS, SCE, Turlock, and Xcel Energy) have a long-term forecast, ranging from week-ahead to month-ahead, in one case.  Updates for long-term forecasts range from every 15 minutes to daily.

- Three Balancing Authorities (AESO, APS, and Glacier) have a separate ramp forecast, although other Balancing Authorities report that a ramp forecast is either under development (CAISO, SCE), as part of their hourly forecast (Northwestern Energy), or in internal research and development (Xcel Energy).

**Table 4. Overview of Variable Generation Forecasting Systems in this Report**

| Balancing Authority | Short-Term Forecast | Medium-Term Forecast | Long-Term Forecast | Ramp Forecast |
|---|---|---|---|---|
| AESO | Began on 12/1/11 | Day-ahead, up to six days | None | Began on 12/1/11 |
| APS | Hourly, updated every 15 minutes | Day-ahead, updated every six hours | Week-ahead, updated daily | Ramp forecasts began in September 2011 |
| BPA | Hourly forecast for next three days, updated hourly | None | None | None |
| CAISO | Hourly forecast for each of the next seven hours, delivered 15 minutes after each hour and at least one hour and 45 minutes before real time | Day-ahead, delivered by 5:30 a.m. day-ahead, predicting each hour of next calendar day | None | None in operation; under development |
| Glacier Wind | Short-term, as often as reasonable (10 minute average data). Hour-ahead up to 86 hours ahead | Day-ahead | Week-ahead | Receive ramp forecast from a third party |
| Idaho Power | Hour-ahead, up to six hours ahead. Plan to reduce this to 30 minutes | Day-ahead Monday through Thursday, 3-day ahead on weekends; up to 5 days ahead, if there is a holiday | None | Maybe, but nothing planned as of yet |
| Northwestern Energy | Hourly, updated every 10 minutes | Day-ahead, updated 6 a.m. and 6 p.m. | None | Part of hourly forecast |
| SMUD | Solar forecast updated hourly, 2-3 hours ahead. Part of CAISO's PIRP for wind | Part of the CAISO PIRP program for wind; none for solar | Part of the CAISO PIRP program for wind; none for solar | Part of the CAISO PIRP program for wind; none for solar |
| SCE | Hourly, updated every 10 minutes next hour, up to 168 hours ahead. Emphasis on next 3 hours. Also participates in CAISO's PIRP for wind | Three times a day, for next hour out up to 168 hours ahead | Once daily, rolling 30 day period | Use short-term forecast ramp indicator, but developing a ramp forecast |
| Turlock | Hour-ahead, updated hourly | Day-ahead, up to five days ahead | Week-ahead | None |
| Xcel Energy | Three hours ahead with 15-minute granularity, updated every 15 minutes | None | Up to week-ahead, updated every 15 minutes with hourly granularity | None, although subject to some internal R&D |

### 3.3 Type, Scope, and Source of Forecasts

The characteristics of each balancing authority affect how the variable generation forecast is utilized, i.e., whether forecasts focus on individual wind or solar plants, individual utility or balancing areas, commercial pricing nodes, or whether they encompass multiple utilities or balancing areas. Those Balancing Authorities with an individual wind plant only needed forecasts for that individual plant (APS, Glacier Wind, Northwestern Energy, and Turlock). Those with multiple variable generation plants in their balancing area forecast for both individual variable generation plants and for the balancing area as a whole (AESO, BPA, Idaho Power, and SMUD [for solar]). The CAISO presently forecasts by plant, by individual utility, and for multiple utilities. The CAISO plans to aggregate forecasts by known renewable energy regions, such as Altamont or Tehachapi. SCE forecasts by individual plant, utility, and region. Xcel Energy's operations extend across individual balancing areas in Colorado, New Mexico, and Texas, and it is a part of Midwest Independent System Operation (MISO). As a result, their forecasts consist of individual variable generation plants and utilities, but also for commercial pricing nodes in MISO.

Table 5 indicates the type of forecasts that each company is either preparing or using. For Balancing Authorities using a third party forecasting company, our interview results may underestimate which forecasts are being prepared. The interviewee may not have been aware of the forecasts the third party forecasting company is preparing. Nearly all of the Balancing Authorities report using (1) a Numerical Weather Prediction (NWP)-based model, (2) persistence, and (3) statistical analysis in preparing their forecasts. Three Balancing Authorities (AESO, APS, and Glacier Wind) utilize a separate ramp forecast. APS began using a ramp forecast in September 2011 and the AESO's ramp forecast became operational in December 2011. Idaho Power reports that its model anticipates ramps reasonably well, but the actual timing of when the ramp occurs may be inaccurate. In addition, Idaho Power reported that its generating resources, being mostly hydro, can respond quickly to commit or decommit units if necessary. Some of the Balancing Authorities thought a ramp forecast should be part of the regular forecasting services provided by a variable generation forecasting company rather than as a separate service.[5]

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[5] The definition of a variable generation ramp event influences the number of variable generation ramps, particularly the time period for defining a ramp. For instance, the number of ramps will increase if the time period for a ramp is 60 minutes as compared to 30 minutes. (Ahlstrom 2011).

**Table 5. Types of Variable Generation Forecasts Being Prepared**

| Balancing Authority | Persistence | NWP Model | Statistical | Weather Situational Forecasts | Ramp Forecasts |
|---|---|---|---|---|---|
| AESO | | X | X | | X |
| APS | | X | X | X | X |
| BPA | X | X | X | | |
| CAISO | X | X | X | X | ** |
| Glacier Wind | X | X | X | X | X |
| Idaho Power | X | X | X | | |
| Northwestern Energy | X | X | X | X | *** |
| SMUD* | X | | | | |
| SCE* | X | X | X | X | ** |
| Turlock | X | | X | | |
| Xcel Energy | X | X | X | | |

\* Also participates in the CAISO's PIRP program
\*\* Under preparation
\*\*\* Part of the hourly forecast

Balancing Authorities report using specific forecasts, persistence in particular, for different applications. BPA blends persistence into its internal and two external wind generation forecasts, with wind generation data that is updated every minute. Xcel Energy also blends persistence into its short-term (under three hours) forecast from 15 minutes to 3 hours, and fully relies on persistence for horizons of <15 minutes, and on NWP-based forecasts for horizons 3 hours and beyond. Idaho Power uses persistence as part of its hourly forecast. Northwestern Energy uses persistence forecasting and relies on its third party forecasting company for determining the boundary conditions. The CAISO uses persistence as part of an internal variable generation forecast, while SMUD uses persistence for its solar forecast. Both Glacier Wind and SCE use persistence as a means of evaluating the performance of third party forecasting companies, and incorporate persistence into their own forecasts. Glacier Wind determines a net benefit (or cost) of the hourly performance of third party forecasting companies as compared to persistence, while SCE expects its vendors to exceed the performance of persistence once models are fully trained. Turlock Irrigation District also uses persistence as a check on the external short-term forecast it receives from its third party vendor.

Five Balancing Authorities develop weather situation forecasts, although the Balancing Authorities are using different approaches and applications. Glacier Wind examines radar, regional surface analysis maps, and other weather products to help prepare situational forecasts. CAISO also assesses weather patterns that can help predict variable generation ramps. It uses weather situational forecasts to train system operators, and uses them as input into a ramp forecasting tool being developed with the California Energy Commission.

## 3.4  Use of Forecasting

Table 6 depicts how variable generation forecasting is used by the Balancing Authorities.  Most of the Balancing Authorities use forecasting for intra-day unit commitment.  About half use forecasts for determining the level of operating reserves.  Five Balancing Authorities also use forecasting for determining usage of hydro and/or gas units, purchases, or storage.  Four Balancing Authorities interviewed use variable generation forecasting for forward unit commitment, although this may reflect the different market positions of the Balancing Authorities being interviewed, as discussed more below.  Glacier Wind uses, and AESO will be using, the day-ahead wind forecast for determining the amount of operating reserves that are needed.  Sometime in 2012, AESO will use both short-term (0-12 hours) and the day-ahead (24 hrs) portion of their medium-term forecast to feed into AESO's Dispatch Decision Support Tool.  It will provide real-time dispatch recommendations to AESO's system operator.

Two Balancing Authorities, Glacier Wind and BPA, reported that they had no plans to incorporate variable generation forecasts into advance or intra-day unit commitment.  BPA noted that since about 80% of wind generation is exported out of BPA's control area, BPA's main use of wind forecasting is to determine its operating reserve needs.  Currently, BPA is not sharing individual wind plant forecasts with individual wind generators, but it will likely do so in the future.  BPA does post an aggregate wind forecast on its website.[6]

**Table 6.  Use of Variable Generation Forecasts by Balancing Authority**

| Balancing Authority | Forward Unit Commitment (Day-ahead, week-ahead, etc.) | Intra-day Unit Commitment | Transmission Congestion Management | Reserves | Management of Hydro or Gas Storage | Generation or Transmission Outage Planning |
|---|---|---|---|---|---|---|
| AESO | | X | | X | | |
| APS | X | X | | | X | |
| BPA | | | X | X | X | |
| CAISO | | X | | | | |
| Glacier Wind | | | | X | | X |
| Idaho Power | X | X | | X | X | |
| Northwestern Energy | X | X | | X | | |
| SMUD* | | X | | | | |
| SCE* | | X | X | | X** | |
| Turlock*** | | | | | | |
| Xcel Energy | X | X | X | X | X | |

\*  Also participants in the CAISO's PIRP program
\*\*  For hydro only, not natural gas
\*\*\*  Uses forecast for trading, optimization, marketing, and compliance with BPA scheduling directives

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[6]  For more information, go to www.bpa.gov/go/windforecast

How variable generation forecasting is used depends, in part, on the circumstances of the balancing authority, so generalizing is difficult. Glacier Wind, for instance, operates a wind project and has no load; therefore, it uses the wind forecast to schedule hourly energy sales, to ensure it has sufficient operating reserves on an hour-ahead, day-ahead, and month-ahead basis, and to schedule planned generation outages for maintenance. Wind plants in BPA's service territory are independently operated and scheduled, and it is up to the wind generators to find buyers and to submit generation schedules to BPA. Because its wind project is outside of its service territory, Turlock Irrigation District uses its wind forecast for trading, marketing, and optimizing schedules. Wind generators in AESO are price takers and do not submit price or bid offers. The AESO plans to use wind forecasts for day-ahead operating reserves, day-ahead and week-ahead resource adequacy, and real time dispatch decisions. Northwestern Energy reports that it uses wind forecasting to determine whether it needs to go into the market to buy additional operating reserves. Northwestern Energy reports that it carries 12 MW of spin and non-spin reserves. However, it will buy another 2 MW if it determines that the Judith Gap wind project is predicted to be at full production.

Two of the utilities that were interviewed report that variable generation forecasting affects how they schedule natural gas purchases and how other generating plants are used. One utility said that variable generation forecasting affects how it uses its hydro plants. For instance, if wind generation is high, but is expected to drop, that utility may use its hydro plants to provide ancillary services. Another utility said that if high wind is predicted, the company will reduce day-ahead gas purchases. If low wind is predicted and the forecast is inaccurate (meaning more wind is generated than forecasted), that utility ends up buying more gas than is needed. In that situation, the utility either has to store it or burn it if the company has a must-burn constraint. The utility may also use its pumped storage unit at night if the forecast calls for high levels of wind production.

## 3.5 Costs and Benefits of Variable Generation Forecasting

About half of the Balancing Authorities provided cost data for their variable generation forecasting systems, but in very different formats, so that makes comparison difficult. Below is an inventory of cost data from the Balancing Authorities that provided information:

- The CAISO charges wind and solar generators $0.10 per megawatt-hour (MWh) and reports that the fee covers roughly all of the forecasting costs.

- Glacier Wind uses multiple wind forecasting companies and pays monthly fees on a project basis. Glacier Wind also receives forecasts for free from some forecasting companies on a trial basis.

- Idaho Power developed its wind forecasting model internally. The company estimated it spent about $500,000 in initial development costs, with half of it coming from internal company funds and the other half from Idaho Power's Smart Grid grant from the U.S. Department of Energy.

- SCE uses multiple variable generation forecasting companies and said the costs are equivalent to two full-time staff people per year.

- Turlock Irrigation District spends between $10,000 and $15,000 annually for wind forecasting or approximately 3 cents/MWh for wind generation.

Other than CAISO, only AESO, among the Balancing Authorities interviewed, levies a charge on wind generators to offset at least part (if not all) of the costs of variable generation forecasts. The AESO rate charged to wind generators is confidential. BPA pays for wind forecasts using funds from a now-expired wholesale green power program. In the future, BPA may incorporate wind forecasting costs into its integration charge, which will be determined in future BPA rate cases.

Only a small number of the Balancing Authorities interviewed attempted to quantify the benefits of variable generation forecasting and each of them used different methodologies. Glacier Wind attempts to quantify the hourly costs and benefits of forecasts versus persistence. Some of the forecasts for Glacier Wind have a consistent monthly price benefit, but others are variable, and when forecasts are not performing well, they can have a negative price impact. Glacier Wind reported that the results are driven by the success, or lack thereof, in the wind forecasts to predict variable generation ramp events. If an upward ramp of variable generation is missed, then Glacier Wind cannot schedule the wind generation and may have to curtail the wind project. If a ramp down is missed, then Glacier Wind has to purchase energy to cover the schedules.

Turlock Irrigation District plans to conduct a cost-benefit analysis of its wind forecast by comparing the performance of the wind forecast versus a persistence forecast. Turlock's analysis will estimate whether the forecast helped reduce wind curtailments or BPA directives to reduce wind production because BPA operating reserves have been exhausted.

With three separate companies operating in different market conditions, Xcel Energy said the benefits of wind forecasting depend on the market conditions. For MISO, Xcel Energy calculates the opportunity cost, defined as the amount that the revenues would have been had the forecast been accurate. In MISO, Xcel Energy determined that the delta between a perfect forecast and the actual forecast range is about $722,000 per the percentage reduction in Mean Absolute Percentage Error (MAPE) per year, based on approximately 1,500 MW of installed wind capacity.

Xcel Energy uses a different methodology for its Public Service of Colorado (PSCO) and Southwestern Public Service (SPS) operating companies since there are no liquid day-ahead or real-time markets in those service areas. Xcel Energy conducts a backcasting analysis where they simulate what actually happened with wind, prices, natural gas, and load with the wind forecast, and then re-run the model with a perfect wind forecast and calculate the value of a perfect forecast. Xcel then estimates the value of an improved wind forecast through reductions in MAPE.

For PSCO, the annual benefit of forecasting is $830,000 per percentage of MAPE. However, the annual value of forecasting drops for SPS to $175,000 per percentage of MAPE. Xcel Energy explained that SPS has a relatively flat load with very large generators. Therefore, it does not have much generation flexibility. In other words, even if SPS had a perfect wind forecast, its generation commitment decisions likely would not change. PSCO, in contrast, has a more flexible system and variable generation forecasting has more value because PSCO can adjust its commitment strategies in response to the forecast (Ahlstom 2011). Xcel Energy expects the

value of wind forecasting in SPS to increase when the Southwest Power Pool (SPP), in which SPS operates, transitions to a location marginal price (LMP)-based market in 2014, as SPP will operate over a larger footprint and will be more flexible as a whole.

AESO stated that wind forecasting is a "no brainer" for them, because a 0.5% to 1% improvement in wind forecasting accuracy results in significant savings, and the benefits of forecasting will easily exceed direct costs. AESO also reported that wind forecasting can reduce the frequency of wind curtailment, with a perfect forecast reducing wind curtailment by 60%.

BPA and Idaho Power both reported that the benefits of variable generation forecasting are hard to categorize and vary over time, making a cost-benefit study difficult. BPA indicated that a major motivation for wind forecasting is to assist in the non-power objectives for the federal hydro facilities they manage, such as irrigation, flood control, and preserving fish populations. SCE also viewed variable generation forecasting as a necessary tool to reduce penalties and imbalances and to assist in making any needed schedule changes.

## 3.6 Data Collection Requirements

Table 7 depicts the data that the individual Balancing Authorities require from wind and, if applicable, solar generators for forecasting. All Balancing Authorities interviewed that engage in wind power forecasting require data on wind speed, wind direction, and turbine location. All except Xcel Energy require temperature and barometric pressure and all except APS and BPA require turbine power output (APS and BPA both receive plant output, not output from individual wind turbines). All of the Balancing Authorities, except BPA, CAISO, and Northwestern Energy, require information on turbine availability. BPA and CAISO receive information on available plant capacity, not on the availability of individual wind turbines. SMUD is a participant in the CAISO PIRP program, which has its own data requirements. About half of the Balancing Authorities interviewed require information on turbine outages, or the wind turbine power curve. Only three Balancing Authorities require solar insolation data, but that likely reflects the lower level of solar capacity as compared to wind.

**Table 7. Data Required from Variable Energy Generators for Forecasts**

| Required Data | AESO | APS | BPA | CAISO | GLACIER WIND | IDAHO POWER | NORTHWESTERN ENERGY | SMUD* | SCE* | TURLOCK IRRIGATION DISTRICT | XCEL ENERGY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind Speed and Direction | X | X | X | X | X | X | X | | X | X | X |
| Temperature | X | X | X | X | X | X | X | | X | X | |
| Barometric Pressure | X | X | X | X | X | X | X | | X | X | |
| Turbine Location (Latitude, Longitude) | X | X | X | X | X | X | X | | X | X | X |
| Turbine Power Output | X | ** | ** | X | X | X | X | X | X | X | X |
| Turbine Availability | X | X | *** | *** | X | X | | X | X | X | X |
| Turbine Outage | X | X | | | **** | X | | | X | X | |
| Wind Turbine Power Curve | X | X | | | | | X | | X | X | X***** |
| Solar Insolation | | | | X | | | | X | X | | |

| | |
|---|---|
| * | Also participants in the CAISO's PIRP program |
| ** | Receives output from wind plant in total, not from individual wind turbines |
| *** | Receives available plant capacity, not availability of individual wind turbines |
| **** | Information on planned outages is provided |
| ***** | Only for first three months of operation, after which Xcel Energy derives a wind turbine power curve from wind generation data. |

Many Balancing Authorities collect other types of data for which they provided explanations, as detailed below:

- AESO requires data on cut-in and cut-out speeds for wind turbines. Data on icing is optional.

- Similarly, BPA asks for information on wind turbine cut-out speeds. BPA also requests information on whether the wind plant is being generation-limited, so BPA knows where wind production may end up once the limit is lifted.

- CAISO asks for back plane temperature from solar systems because solar plant efficiencies decrease as the panel temperature increases.

- For wind turbines, CAISO's wind forecasting provider uses an algorithm to determine the optimum number and location of turbines from which it collects data.

- Glacier Wind provides curtailment information. They also collect data from off-site met towers.

- Idaho Power derives the wind turbine power curve from its forecast model. Idaho Power compares the model's estimated turbine power curve to what wind generation companies are reporting, then ties the model to individual turbines that are closest to the model predictions.

- Xcel Energy requires a turbine availability forecast in real-time, consisting of wind speed, turbine production and availability, and a forecast of day-ahead turbine availability in aggregate (i.e., 95% of the turbines are available and in service).

- SMUD's solar persistence forecast relies heavily on photovoltaic output data.

Balancing Authorities were asked if there were requirements for how the data is to be collected, as shown in Table 8.  AESO prefers to have data from meteorological (met) towers, as opposed to plant-mounted sensors. They stated that data from plant-mounted sensors can be affected by the movement of the wind turbine blades.  In contrast, Xcel Energy prefers plant-mounted sensor data for its granularity. Although, Xcel Energy does accept met tower data and requires new large wind projects to have a met tower.  BPA, SCE, and Turlock require data from both met towers and plant-mounted sensors. Glacier Wind prefers met tower data, but it also uses plant-mounted sensor data.  Northwestern Energy and SMUD installed met towers to help with data collection. APS does not have any data collection requirements.  Idaho Power has relied on historical wind resource data from the Idaho National Laboratory, scaled from 30 to 80 meters. It now requires new wind projects not certified as qualifying facilities, under the Public Utility Regulatory Policies Act (PURPA) of 1978, to have a met tower.

**Table 8. Requirements for Sources of Data for Variable Generation Forecasting**

| Balancing Authority | Met Tower | Plant-Mounted Sensors | Other Requirements | Comments |
|---|---|---|---|---|
| AESO | X | | Minimum of one met tower; data to be provided to AESO every 10 minutes. Must be at hub height for new wind projects | Prefers data from met towers, as data from plant-mounted sensors can be affected by the wind turbine blades |
| APS | | | | No real requirements; evaluating views from wind forecasting companies that only historical output from wind projects is needed |
| BPA | X | X | One met tower per wind plant and data from a sample of nacelles | Data requirements just put in place |
| CAISO | X | X | Require two met towers for newer wind projects (algorithm for selected wind turbines) | |
| Glacier Wind | X | X | | Prefers met data, but collects data from individual turbine sensors as well |
| Idaho Power | X (for new wind projects) | | | Use historical data from Idaho National Laboratory. Met tower requirements imposed on non-PURPA projects but not generally on PURPA projects |
| Northwestern Energy | | | | Northwestern Energy put in two met towers to help with forecasting |
| SMUD | | | | SMUD put in a metrological tower to help with forecasting |
| SCE | X | X | Requires met tower for every 50 MW; may decrease to 25 MW | Requires data sources to be calibrated for accuracy at least once per year |
| Turlock Irrigation District | X | X | | Has two met towers at its wind project |
| Xcel Energy | X (for new large wind projects) | | Recently began requiring large wind projects to have a met tower | Prefer plant-mounted sensor and nacelle data to met towers, as it is more granular, but will accept data from met towers |

None of the Balancing Authorities reported much difficulty in getting the data they need. Providing data is a condition of grid interconnection, and failure to provide data can be referred to the Federal Energy Regulatory Commission (FERC) for action. SCE said data requirements and data performance quality requirements are part of power purchase agreements with SCE, and the agreements allow SCE to reduce power purchase rates if those requirements are not met. AESO said it may consider penalties in the future for failure to provide data.

Both the CAISO and Xcel Energy reported that the older wind projects have more difficulty in transmitting data, because their supervisory control and data acquisition (SCADA) systems are antiquated and not compatible with the data systems of the transmission operator or utility receiving the data. Xcel Energy reported that it was receiving data from 84% of wind capacity, with 91% being the most that it could receive data from. Xcel Energy indicated the gap between 84% and 91% is for new wind projects that Xcel Energy is not receiving data from yet, but it expects to in the near future. The remaining 9% are small projects below 10 MW or grandfathered projects that were built before 2003 and do not have compatible data communication systems with Xcel Energy. Glacier Wind reported some data transmittal problems, due to network connectivity interruptions. Turlock Irrigation District has experienced occasional communication issues that have affected the operation and control of the wind project.

## 3.7   Sources of Variable Generation Forecasts and Performance Guarantees

Balancing Authorities were asked whether they contract with a third party provider for forecasts or prepare the forecasts themselves. Three Balancing Authorities (Idaho Power, SMUD for solar generation, and Xcel Energy) prepare the forecasts internally, although Xcel Energy's forecast is maintained by a private third party under a service agreement. Five Balancing Authorities (AESO, APS, CAISO, Northwestern Energy, and Turlock Irrigation District) each contract with a third-party vendor. BPA, Glacier Wind, and SCE use multiple forecasting companies. In addition, both BPA and CAISO have internal forecasts they have developed in addition to the forecasting services they receive from third-party vendors.

Few of the Balancing Authorities either knew or were willing to provide information on whether there were performance requirements or incentives for third party forecasting companies. The CAISO has an incentive plan if forecasting errors are at or below certain target levels, grouped by four regions. BPA said the performance of the wind forecasting company is evaluated within a prediction interval (i.e., upper and lower bands). BPA wants the prediction interval to be as small as possible and actual generation to stay within the interval as much as possible. Forecasts at BPA are also evaluated on average error and peak error over evaluation intervals.

Glacier Wind has not defined a performance metric, although such a metric is under internal discussion. Glacier Wind wants at least one forecast per hour and said ramping is its primary concern. The company wants the wind forecasting's ramping predictions to be more accurate than what can be achieved with a persistence forecast. Glacier Wind also said that forecasting companies that do well in ramping forecasts can have a consistent bias in their forecasts, and Glacier Wind would like that bias to be removed in designing and implementing any forecasting metric.

By contrast, AESO does not have a forecast accuracy requirement with Weather and wind Energy PROGnosis (WEPROG), its wind forecasting company, although such a requirement may be implemented in future contracts with WEPROG or a subsequent wind forecasting company. AESO wants to establish a baseline and get some experience with wind forecasting before considering any such performance requirements or incentives.

## 3.8  Ensemble Forecasts and Confidence Intervals

Most of the companies interviewed rely on (or receive) ensemble forecasts. Ensemble forecasts can either be forecasts from multiple forecasting companies (as is the case with BPA, Glacier Wind, and SCE), or a forecast from a single vendor based on multiple forecasts from the same vendor but with changes in the initial conditions of the forecasting model. Six of the companies interviewed have confidence intervals in their forecasts, with others considering the use of confidence intervals. Variable generation forecasts may include confidence intervals to provide a range within which to expect wind generation. Although dependant on actual conditions, a general trade-off with confidence intervals is the higher the confidence interval, the larger the potential range of outcomes. It appears that some Balancing Authorities are using probabilistic forecasting, although several of the Balancing Authorities we interviewed rely on third party vendors for forecasts, and this result may be because of a lack of familiarity with how their vendors prepare their forecasts. More details are provided below and in Table 9.

- AESO reports that WEPROG prepares 13 different forecasts that can be grouped based on site-specific data used for short-term forecasts, or forecasts that do not rely on site-specific data used for longer-term forecasts. AESO uses a minimum and maximum band, and 80%, 95%, and 98% confidence intervals. AESO notes that the difference between the minimum and the maximum bands can be quite large.

- APS' wind forecasting vendor uses an ensemble approach in producing a forecast. APS is considering using confidence intervals for an upper and lower limit, although they are not using confidence intervals currently.

- BPA uses three forecasts, one prepared internally and two from third party forecasting companies, who also prepare probabilistic forecasts. BPA's final forecast is generally a blend of probabilistic, persistence, and ensemble forecasts. BPA started with a 95% confidence interval, but has switched to a maximum and minimum confidence interval provided by the forecasting companies. The intervals can be wider during wind events or with high uncertainty about forecasts, or can be narrower during times of low or predictable wind production.

- CAISO receives a confidence interval for day-ahead forecasts; however, it does not apply it because CAISO does not currently use the day-ahead forecast. No confidence interval is prepared for the hour-ahead forecast. CAISO plans to examine whether it should use a confidence interval.

- Glacier Wind relies on multiple wind forecasting companies and has utilized probabilistic wind forecasts, but is evaluating whether to continue with those types of forecasts. Several of Glacier Wind's forecast providers use and provide ensembles. Glacier Wind reports that some "human ensemble forecasting" is occurring when the company examines the different wind forecasts and makes operating decisions based on the forecasts. The company says it

also takes advantage of free trials by wind forecasting companies to evaluate their capabilities.

- Idaho Power does not use a probabilistic forecast or a confidence interval currently, but expects to apply a confidence interval for its day-ahead forecast in the future. The company currently does four model runs every six hours (midnight, 6:00 a.m., noon, and 6:00 p.m.) for both day-ahead and hour-ahead models, and proportionally weighs the models equally. That is, for the midnight run, the model incorporates present conditions plus the three previous model runs. Idaho Power may consider using different weights for the model in the future.

- Northwestern Energy's wind forecasting vendor prepares multiple forecasts and accounts for past forecast performance in preparing a forecast for Northwestern Energy. The vendor also uses a confidence interval, although Northwestern Energy was uncertain what it was.

- SMUD is not doing probabilistic forecasting with its solar forecast, but may in the future.

- SCE uses several third-party variable generation forecasting vendors but could not supply the names or the number of companies it uses due to non-disclosure agreements. SCE uses multiple confidence intervals, at 10% increments, depending on the particular circumstances.

- Turlock Irrigation District's wind forecasting company provides a revised forecast daily out to seven days ahead. The wind forecast is based on several variables including wind speed, wind direction, barometric pressure, turbine capacity, and various algorithms.

- Xcel Energy's wind forecasting models are not probabilistic, but Xcel Energy may perform different model runs with a low, medium, and high wind forecast, and then choose one. Xcel Energy uses a 75% confidence interval around the expected forecast.

**Table 9. Use of Ensemble Forecasts and of Confidence Intervals**

| Balancing Authority | Use of Ensemble Forecasts | Use of Confidence Intervals | Comments |
|---|---|---|---|
| AESO | X | X | |
| APS | X | | Considering using confidence intervals. |
| BPA | X | X | |
| CAISO | X | | Receives a confidence interval from its forecasting company, but does not apply it. Considering whether to use a confidence interval. |
| Glacier Wind | X | X | Re-evaluating probabilistic forecasts. |
| Idaho Power | | | Expects to use a confidence interval in the future for its day-ahead wind forecast. |
| Northwestern Energy | X | X | |
| SMUD | | | May do probabilistic forecasting in the future with solar forecasts. |
| SCE | X | X | |
| Turlock Irrigation District | | | |
| Xcel Energy | X | X | |

## 3.9 Incorporating Curtailments and Outages into the Variable Generation Forecast

The incorporation of variable generation curtailments and outages into variable generation forecasts has not always occurred regularly, with detrimental impacts on variable generation forecasting performance. Wind turbine availability is sometimes assumed at 100% in wind power forecasting models, and information on wind turbine availability is often unavailable or unreliable for incorporation into wind power forecast models.

Each of the Balancing Authorities interviewed are confronting the issue differently. Any curtailment or redispatch orders from BPA are transmitted to the wind plant and then returned for incorporation into BPA's wind forecast. Until the summer of 2011, APS was receiving turbine availability information but not day-ahead planned turbine outages or outages due to grid faults. Now, wind facilities provide day-ahead planned outage schedules to APS' variable generation company, and a forecast is prepared with and without the wind turbines that are scheduled to be out of service.

AESO is transitioning to wind projects that report real-time limits, turbine availability by plant, total plant availability, and wind power management limits every 10 minutes through a business-to-business data exchange. The data is time stamped and sent to WEPROG in Denmark, which prepares the wind forecast and sends it to AESO. SCE incorporates turbine outages, availability,

and total wind capacity potential and transmits the information to variable generation forecast providers. SCE also asks for data on nacelle position, blade position, and the number of anemometers at each turbine. The CAISO's interconnection tariffs require variable energy generators to provide information on equipment and plant availability. The CAISO has an automated system for variable energy generators to report MW availability. This information is passed along to their variable generation forecast vendor. Turlock Irrigation District reports information on turbine outages and availability to its wind forecasting company, but not curtailments or redispatch orders from BPA. For solar generators within their service territory, SMUD asks for scheduled outages, if solar generators have any unscheduled outages, and when the solar plant is expected to go back on-line.

Xcel Energy factors in turbine outages when the data is reported, but data is not always provided regularly or on a consistent time frame. Xcel Energy does not factor in curtailments; instead, it incorporates uncurtailed forecasted wind production, as adjusted for turbine availability, into an energy dispatch model to determine whether there will be wind curtailments. If wind curtailments are projected, then Xcel Energy will re-run the model and will consider decommitting additional conventional generation units, if reliably and economically feasible, and then inform the real-time operator whether or not wind needs to be curtailed.

Glacier Wind believes it is cumbersome for wind forecasters to have to predict turbine availability, turbine outages, and wind curtailment. The company asks the forecasters to forecast wind generation, excluding the impact of outages or curtailments. Glacier Wind adjusts the forecasts based on its most up to date knowledge of planned wind capacity.

Idaho Power does not factor in turbine outages because wind curtailments are relatively infrequent and do not have significant impact on the wind forecast. Idaho Power may incorporate wind curtailment into its wind forecasting model in the future.

## 3.10 Assessing Accuracy of Variable Generation Forecasts

Balancing Authorities used a variety of methods in evaluating the performance of variable generation forecasting companies. APS, SMUD, and Turlock Irrigation District did not have forecast error information available.

CAISO, Idaho Power, and Northwestern Energy use the Mean Absolute Error (MAE), and results are reported below in Table 10. Caution should be used in interpreting the data. The data in Table 10 encompass different time periods, making comparisons difficult. Also, many wind power forecasting systems have not been in operation for long. Added to that, wind power forecast performance may vary significantly (5% or more of the installed capacity of wind) because of location, season, and weather regime. Some weather regimes are also more sensitive to small variations in the start-up conditions of the wind power forecast. Therefore, small differences in current weather conditions can lead to large differences under future weather conditions. In these weather regimes, the performance of wind power forecasting systems is generally not as good as weather regimes with less sensitivity. Additionally, frequently used metrics such as MAE and Root Mean Square Error (RMSE) assume the forecast errors follow a normal distribution, when they often have asymmetric distributions and distribution shapes that vary with time.

**Table 10. Mean Absolute Error for Wind Forecasts for Various Balancing Authorities and Time Frames**

| Balancing Authority | Time Period | MAE: Forecast Description | MAE |
|---|---|---|---|
| CAISO | Historical average | Hour-ahead and day-ahead | <10% hour-ahead <br> <15% day-ahead |
| Idaho Power | April-August 2011 | Day-ahead | 12.2% |
| Northwestern Energy | 2010 | Two hours ahead, Day-ahead | 11.8% two hrs ahead <br> ~14% day-ahead |
| Public Service of Colorado | 2008-2010 | Day-ahead | 19.4% in 2008 <br> 18% in 2009 <br> 14.3% in 2010 |
| Northern States Power | 2008-2010 | Day-ahead | 18.7% in 2008 <br> 15.7% in 2009 <br> 12.2% in 2010 |
| Southwestern Public Service | 2009-2010 | Day-ahead | 16.4% in 2009 <br> 14% in 2010 |

AESO and Xcel Energy calculate the MAPE that subtracts the forecasted wind generation minus actual wind generation for each hour, divided by the maximum continuous rating of the wind projects. These results are presented in Table 11. Xcel Energy provided information for each of its utility subsidiaries (PSCO, Northern States Power, and SPS). AESO reported a relatively flat forecasting performance and hopes to improve it with the inclusion of site-specific meteorological and production data that it now requires.

**Table 11. Mean Absolute Performance Error for Wind Forecasts for Various Balancing Authorities and Time Frames**

| Balancing Authority | Time Period | MAPE: Forecast Description | MAPE |
|---|---|---|---|
| AESO | Historical average since January 2010 | Day-Ahead | 13% day-ahead |
| Public Service of Colorado | 2008-2010 | Day-ahead | 19.4% in 2008 <br> 18% in 2009 <br> 14.3% in 2010 |
| Northern States Power | 2008-2010 | Day-ahead | 18.7% in 2008 <br> 15.7% in 2009 <br> 12.2% in 2010 |
| Southwestern Public Service | 2009-2010 | Day-ahead | 16.4% in 2009 <br> 14% in 2010 |

BPA uses several metrics in evaluating the performance of wind forecasters. BPA measures for the average wind forecast error and peak wind forecast error over several defined intervals. BPA looks at the top five peak wind forecast errors, regardless of the time and day they occur. BPA considers the number of hours when the wind forecast error was zero, but excludes hours when wind is not generating. BPA also calculates the number of hours when wind forecast error (in

MW) was higher than up and down balancing reserve requirements.  BPA, on average, has about 900 MW of up reserves and 1,100 MW of down reserves, although it varies month to month. BPA conducts case studies to determine which wind forecasts perform the best during system events, such as transmission problems or large plants going out of service.  Finally, as noted before, BPA measures how often wind forecasting company forecasts are within the maximum and minimum forecast intervals, and how wide or narrow the interval.

Glacier Wind uses both MAE and RMSE, and compares the error of the wind forecast versus that of persistence.  The best they report is a 10% improvement over persistence, at 75 minutes ahead of real-time.  Glacier Wind notes that MAE and RMSE track small changes that may not be as problematic, but they do not adequately emphasize large events.  To quantify the performance for ramp events, Glacier Wind uses the equitable threat score, which quantifies the relative skill of detecting ramp events while penalizing false predictions.

SCE uses RMSE and says the value ranges from 13% to 20%, with real time closer to 13% and day-ahead closer to 20%.  They expect the RMSE will be below 10% with increasing experience and tuning of the forecasting models.

## 3.11  Future of Variable Generation Forecasting in the West

This part of the phone survey asked Balancing Authorities what they considered the strengths and weaknesses of variable generation forecasting; what advice they would give other Balancing Authorities who are thinking of implementing forecasting; how their use of forecasting has changed over time and may change in the future; and any recommendations they may have for the West as a whole regarding variable generation forecasting.

Some of the Balancing Authorities mentioned that variable generation forecasting is helpful, but that it should be either discounted or viewed with caution.  The CAISO stated that the accuracy of variable generation forecasting tends to be compared to the accuracy of load forecasting, but forecasting variable generation is much different than forecasting for load.  Load, at least in the CAISO, is always above 20 GW, whereas variable generation will have more range between the minimum and maximum outputs.

Northwestern Energy reports that it uses wind forecasting as a guide, but not as a hard target because the forecast errors can be high.  Further, it expects wind forecasting to improve, but that predicting the peaks and valleys of wind power output can be difficult.  Turlock Irrigation District reports that it also discounts its wind forecast and recommends comparing forecasting performance with that of persistence forecasts. Its wind forecasts have improved over time with the incorporation of historical wind output data that has helped train the forecasting model. Glacier Wind recommends comparing wind forecasts to persistence forecasts and to use a ramping-oriented metric, such as an equitable threat score.  An advantage of wind forecasting, according to Glacier Wind, is that day-ahead wind forecasts provide some context of what is about to happen, even though there may be errors in timing and magnitude.  Glacier Wind notes that a weakness of wind forecasting is that there can be large errors in the hour-ahead or intra-hour, requiring the company to do some hedging around the forecast.  They report some issues with probabilistic wind forecasting in that there is not a lot of difference in the sharpness of the

probabilistic forecast spread from hour to hour. Idaho Power reports that, in general, the day-ahead wind forecasts are good, but they are inaccurate about one day in every 10.

Xcel Energy has found that wind power has an element of predictability to it and that the publicly available NWP models are pretty good. However, the amount of investment necessary to improve from "pretty good" to "really good" is more significant. Xcel Energy reports that the investment has been worthwhile, with a return on investment in less than a year, due to reduced forecasting errors.

Other Balancing Authorities mentioned data as a key to variable generation forecasting. AESO said real-time and site-specific meteorological data, turbine availability, turbine maintenance scheduling, known curtailment limits, and transmission limits are critical for improving forecasting accuracy. APS notes that their wind forecasts are not as accurate as anticipated because turbine outage scheduling was not being incorporated into the forecasts, and there are delays in transmitting intra-hour data from the wind projects. The CAISO recommended that WECC consider adopting standards for data collection from variable generation projects.

BPA reports that wind forecasting has helped it determine the type (up/down reserves) and magnitude of operating reserves that will be deployed in the near future. BPA explained that it is continuing to refine its wind forecasting needs as wind continues to be developed in its balancing area. They benefit from having more than one wind forecasting vendor, because each company does forecasting differently and excels under different circumstances, time horizons, or for specific projects. BPA reports that it is still in a learning and development phase and is moving towards a blended forecast and possibly intra-hour forecasting in the future. BPA noted it is in a unique situation compared to other Balancing Authorities because it is forecasting for over 30 wind plants, with possibly another 15 wind plants coming online in the next few years, bringing the total wind capacity in BPA's balancing area to over 6,000 MW.

SCE reports that variable generation forecasting can be helpful, once historic and real-time weather data and production data are incorporated into the model and the model is trained. However, it takes time (typically a year) to put the data collection processes in place and to train the model. SCE also notes that the forecasting model needs to be checked periodically to ensure data consistency and quality. Dropped data or a stuck data value can affect the quality and accuracy of the variable generation forecast.

Only a few Balancing Authorities are using solar forecasting because the amount of installed solar capacity is less than installed wind capacity. Four Balancing Authorities, APS, CAISO, SMUD and Xcel Energy, reported that solar forecasting is at an early stage. APS and SMUD note that solar's daily resource shape is effectively the same, and easily predictable under clear-sky conditions. For APS, these clear-sky conditions are present about 300 days a year. Both APS and SMUD explain that solar plant-to-plant variability can be high and they hope that the variability will be minimized with regional aggregation of multiple solar projects. SMUD has applied to the California Public Utilities Commission's California Solar Initiative Research and Development Program for a grant to study and validate five different solar forecast providers. CAISO questions whether satellite data alone will be sufficient for solar forecasting, or whether data will also need to be gathered from ground-based systems.

Few Balancing Authorities had recommendations for other Balancing Authorities who are considering variable generation forecasting, other than a general recommendation to start sooner rather than later, as it can take time to plan, prepare, and train the forecast. Idaho Power, for example, said limited financial and personnel resources prompted them to plan and design their forecasting system in-house. SCE suggested not relying solely on in-house forecasting, as variable generation forecasting vendors can leverage multiple tools and can help with quality control and after-the-fact analysis. SCE also believes that in-house variable generation forecasting systems can become stagnant, particularly if internal funding or personnel devoted to forecasting decreases. SCE recommended siting multiple meteorological towers if the wind project is especially large or covers a lot of land. BPA suggested making the Information Technology (IT) infrastructure sophisticated and robust enough to receive data directly from the forecasting vendor, instead of having to go to the forecasting company's website, and to enable switching to different forecasting companies, if necessary. BPA also suggested trying different forecasting companies because each forecasting company has different strengths and weaknesses.

Several Balancing Authorities explained that their use of variable generation forecasting has changed since it was first implemented. SCE began with a persistence-only forecast. Then, it added historical variable generation, data from production and meteorological towers, and other data on the availability and location of variable generation projects. Xcel Energy explained that they previously included simplified forecast day-ahead planning prior to the large increase in wind installations on their system. Now, Xcel Energy fully utilizes its wind forecasting system in all facets of its operations and short-term planning processes. Xcel Energy also has enough confidence in its wind forecast that if they expect to curtail wind, they will send out a warning ahead of time and may decommit a fossil generating unit or try to sell excess power off its system. Idaho Power is also confident in its wind forecasting system and uses it in planning to commit or decommit units, increase or decrease hydro production, or make trades. Conversely, Turlock reported that they initially trusted their wind forecast more, but now compare wind forecasts with historical production records. If the two differ significantly, Turlock relies on historical production records or uses some mix of the forecast and historical production. APS noted that they did not save their historical wind forecasts until recently. Now, they use historical wind forecasts to conduct "backcast" analyses to evaluate the performance of the wind forecasts. Glacier Wind did not correct wind forecasts for turbine availability or for curtailment initially, but they do now. Glacier Wind also installed an off-site meteorological tower two years ago after first mapping the areas with the largest wind forecast error. The meteorological tower is about 45 miles away from the wind project and has improved the ramping up forecasts of wind production. AESO changed its forecasts to focus on short-term, instead of long-term forecasts, and require site-specific production and met data.

Several Balancing Authorities plan future improvements to their variable generation forecasting systems. CAISO expects to transition to a probabilistic forecast and, perhaps, incorporate a separate ramp forecast. Northwestern Energy is also considering adding a separate ramp forecast. Two Balancing Authorities, APS and Northwestern Energy, have contracts with third party forecasting vendors that will expire in the near future, and both companies are considering their options. AESO may require more data for ramp forecasting. SMUD is considering developing shorter-term forecasting tools for dispatching storage.

There is support for more coordinated variable generation forecasts among multiple Balancing Authorities, but most expressed skepticism that it will happen without a requirement or some sort of forcing function.  No one who was interviewed is currently sharing forecasts outside their own balancing authority, although SCE and CAISO share forecasts because SCE is in CAISO's Participating Intermittent Resource Program.  SMUD thought forecasting solar regionally would be very helpful and would assist in improving solar forecast accuracy. AESO agreed that sharing forecasts among balancing areas would help with day-ahead resource planning and for situational awareness.  APS and Glacier Wind thought sharing variable generation forecasts among balancing areas would not have much value unless there is greater balancing area coordination for ancillary services, energy imbalances, or other coordination mechanisms, such as sharing Area Control Error (ACE) through the ACE Diversity Interchange.  Xcel Energy noted that a regional forecast may be useful to address the points mentioned, but also indicated there is commercial sensitivity around the forecast information that is collected and owned by individual companies. If more regional coordination occurs, APS, Glacier Wind, and Xcel Energy explained that sharing variable generation forecasts (or an independent regional forecast, as Xcel Energy suggested) would make more sense.  SCE would like more effort at sharing wind production and meteorological data among multiple parties through grid data networks.

# 4   Comparing Variable Generation Forecasting in the West with "Best Practice" Variable Generation Forecasting

This section compares and contrasts variable generation forecasting in the West with those who employ "best practices" elsewhere in the United States.  The term "best practices" was used somewhat loosely for this project, neither the National Renewable Energy Laboratory (NREL) nor the Western Interstate Energy Board offer recommendations on the criteria for "best practices" in variable generation forecasting.  Our criterion to determine the use of "best practices" is that a separate ramping forecast is in service or that the variable generation forecast is relied upon for energy schedules and dispatch, at least in real-time.  Ultimately, we selected the Electric Reliability Council of Texas (ERCOT) and MISO as employers of "best practices." ERCOT has a separate wind ramp forecasting tool, in addition to its regular wind forecast. ERCOT also uses wind forecasting to determine the need for Non-Spinning Reserve Service. MISO uses wind forecasts in its real-time market, as explained in more detail below.

After first describing how ERCOT and MISO utilize wind forecasting, a comparison of wind forecasting in the Western Interconnection with that of ERCOT and MISO follows.

## 4.1   Electric Reliability Council of Texas

ERCOT serves 85% of the load in Texas, geographically representing 75% of Texas. As of August 2011, ERCOT had a generating capacity of 84,731 MW to meet a peak demand of 68,379 MW. The installed wind capacity represents 9,420 MW, or approximately 11% of ERCOT's total generating capacity.[7]

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[7] The total installed wind capacity in Texas as a whole, including ERCOT and non-ERCOT areas, is 10,135 MW as of August 2011.

ERCOT contracted with AWS Truepower for a centralized wind power forecasting system that became operational in July 2008. The wind power forecast system provides the Short-Term Wind Power Forecast (STWPF), which is an hourly 50% probability of exceedence forecast for the upcoming 48 hour period. The STWPF produced for each wind-powered generating resource (WGR) is updated hourly and delivered 15 minutes past the hour. An 80% probability of exceedence forecast is also provided, but it is used primarily for situational awareness.

Several WGR-specific parameters and observation data must be given to AWS Truepower as input for developing the wind forecast. The required data includes the capacity rating and model of each wind turbine, the total number of wind turbines, the average turbine hub height, the geographic location of the center of the wind plant, power output observations, observed wind turbine outages and availabilities, net output capabilities, curtailment alerts, and meteorological data with the instrumentation height and geographical location (wind speed, wind direction, barometric pressure and temperature). ERCOT does not require that the data come from either a meteorological tower or plant-mounted sensor. ERCOT will assess whether the provided wind speed data and wind production data is correlated, and if the correlation is low, ERCOT will require the WGR to find another location for providing the wind speed data.

In preparing a forecast, AWS Truepower uses a composite of the individual members of an ensemble of forecasts for each wind project in the ERCOT territory. AWS Truepower uses three NWP models, one that is run every three hours and two that are run every six hours. AWS Truepower also incorporates a wind resource output model that uses both wind production data and data derived from wind turbine power curves.

AWS Truepower ultimately plans to run a nine NWP model ensemble every six hours and a single NWP model every hour, known as a Rapid Update Cycle. AWS Truepower will weigh ensemble members according to performance in a rolling training sample. AWS Truepower also uses a statistical power output model that incorporates all wind generators that provide sufficient data.

During day-ahead and hour-ahead operations, Qualified Scheduling Entities (QSE) representing wind resources must use the most recently provided STWPF as the planned high sustainable limit in their Current Operating Plans (COP). The COPs are then used in both the Day-Ahead and Hour-Ahead Reliability Unit Commitment Studies that ensure enough capacity is available to serve the forecasted load. QSEs are expected to adjust the provided forecasts for unreported unavailability of wind turbines. In the operating period, any remaining hour-ahead wind (and load) forecasting errors can be addressed using the Non-Spinning Reserve Service (NSRS), a 30-minute service provided by offline generation resources, online generation resources with available capacity, and load resources. Requirements for NSRS are determined using historical Net Load (load minus wind) forecast errors.

When moving into the operating hour, ERCOT's Security Constrained Economic Dispatch (SCED) will produce individual dispatch instructions for all generation resources, generally at a five-minute frequency. These dispatch instructions are primarily based on real-time telemetry, resource offers, and system conditions. The SCED assumes persistence for all uncurtailed WGRs and, therefore, considers the WGR's net power output to remain constant throughout the five-minute dispatch interval. Any actual changes in the WGR's net output that occur during the

dispatch interval will be offset using ERCOT's regulation service. Regulation requirements are determined using historical five-minute variations in wind generation and load, and accounting for any increases in installed wind capacity. A WGR must also telemeter its net output capability so that if a WGR is curtailed, ERCOT can know what the WGR could be producing if it was released from curtailment. During intervals in which a WGR is required to lower its generation output as a result of the SCED dispatch, a directive is sent out by ERCOT to indicate this to the QSE. The forecasts provided by AWS Truepower do not reflect projected wind curtailment, but AWS Truepower receives wind curtailment observations and uses them as input into the wind forecasting model and for statistical analysis.

In addition to WGR power forecasts, AWS Truepower provides ERCOT with a ramp forecasting tool called the ERCOT Large Ramp Alert System (ELRAS). ELRAS forecasts probabilistic ramping events of a predefined magnitude and duration. The application also generates 15-minute regional and system-wide forecasts for an upcoming six hour period, updated every 15 minutes. At present, the ramp forecasts provided by ELRAS are used by ERCOT's system operators for situational awareness.

Lastly, ERCOT's system operators will have access to an additional situational awareness application once development is complete. The ERCOT Risk Assessment Tool (ERAT) can be used from day-ahead to hour-ahead operations and is expected to reveal periods with high risk of a loss-of-load event. While considering forced outage rates in addition to load and wind forecast uncertainties, the assessment will determine risk levels associated with the following three scenarios: planned online generation, planned online generation with responsive reserve, and planned online generation with demand response and non-spinning reserves. Once fully operational, ERAT could potentially provide additional information for Reliability Unit Commitment studies or to help determine ancillary services requirements, or both.

## 4.2  Midwest Independent System Operator

The MISO footprint covers all or parts of North Dakota, South Dakota, Minnesota, Iowa, Wisconsin, Illinois, Indiana, Michigan, Montana, Missouri, and Kentucky. MISO has a total available generating capacity of 131,010 MW, and about 10,680 MW of installed wind capacity. On July 20, 2011, MISO had a record peak demand of 103,975 MW.

MISO began using centralized wind power forecasting in June 2008. Energy & Meteo Systems, the company that performs wind forecasting for MISO, prepares its forecasts for four different levels with three NWP models that are weighted according to the weather situation and historical performance, site-specific power curves based on historical data, and a shorter-term model (0-10 hours) based on wind power measurements and input from a NWP model. The four levels are commercial pricing (CP) nodes, zones, regions, and all of MISO. The CP nodes typically signify a single wind project, while the regions match up geographically with MISO's reliability regions (East, Central, and West), and the zones represent smaller areas, such as states. Energy & Meteo also provides a wind power forecast of the optimal combination of all three NWP model forecasts.

MISO receives five minute granular forecasts for each CP node, and updates are provided for the next six hours at five minute intervals. MISO also receives hourly updated forecasts for each

hour beyond six hours for the next six and one-half days. MISO does not currently have a ramp forecast, but it is considering whether to adopt one. The wind power forecast in the MISO is used for next-day and multi-day-ahead transmission security planning (also coordinating with the PJM and SPP wind power forecasts) and outage coordination, as well as next-day and intra-day reliability analysis. MISO also uses the wind power forecast to project the impact of wind variability on transmission flowgates and to manage transmission constraints. MISO, PJM, and SPP share their wind power forecasts for coordinating transmission security between the three Regional Transmission Organizations (RTOs).

All wind resources in operation after April 1, 2005, and not delivered under network or long-term point-to-point transmission service, must register as Dispatchable Intermittent Resources (DIR) by March 1, 2013. Wind generators registered as Qualifying Facilities under PURPA are exempt. MISO refers to wind generators not registered as a DIR as Intermittent Resources.

In the real-time market, DIRs must submit a five-minute wind forecast at the CP node level, or accept the MISO's default wind forecast. MISO's default five-minute forecast is the same forecast whether it is for a Dispatchable Intermittent Resource or an Intermittent Resource. The MISO default wind forecast is also used if the DIR's forecast is over 30 minutes old or exceeds the feasibility limit of the wind plant. DIR forecasts up to 110% of the feasibility limit are accepted. DIRs can update their forecast maximum limit up to 10 minutes before each scheduling interval (i.e., up to 15 minutes ahead). If a DIR chooses to use the MISO-provided five- minute wind generation forecast values on its CP Node, this forecast value will be used as the economical maximum limit for the wind plant in the dispatch function.

MISO will curtail Intermittent Resources during minimum generation events after using the emergency range (between economic minimum and emergency energy minimum) of conventional generation. MISO curtails Intermittent Resources out of market for transmission congestion and minimum generation events. The order of curtailment is based on the impact on the transmission constraint and priority of transmission service. During normal operation, MISO will dispatch DIRs with a lower offer price than the market clearing price to their maximum level, and to their minimum level if the DIR offer price is higher than the market clearing price. If there is transmission congestion and DIRs have similar impact on a constraint, MISO will first curtail DIR projects with higher offer prices.

MISO pays for wind power forecasting, and market participants are required to provide non-binding, day-ahead resource forecasts to MISO. These forecasts consist of an hourly forecast of projected next-day output and are not currently used for dispatch purposes. For each wind plant, MISO provides Energy & Meteo Systems with the latitude and longitude, the hub height, the maximum and historical MW output, and the real-time output. Information on wind turbine outages and curtailments is passed on to Energy & Meteo every five minutes and this information is used in Energy & Meteo's combined forecast from its three NWP models.

## 4.3 Comparison and Contrast

In general, use of variable generation forecasting by Balancing Authorities is a relatively recent phenomenon across the country, not just in the Western Interconnection. Balancing Authorities are learning the capabilities of their variable generation forecasting systems and determining what improvements and changes need to be made. In this section, the state of variable generation forecasting in the West is compared and contrasted with that of ERCOT and MISO.

### 4.3.1 Geographic Scope and Balancing Area

A noticeable difference between variable generation forecasting in ERCOT and MISO and in the Western Interconnection is the difference in geographic scope and the size of the balancing area. As noted earlier, ERCOT serves most of the load and most of the geographic area of Texas, while MISO covers all or parts of 13 states. Both ERCOT and MISO operate as single balancing areas. In contrast, the Western Interconnection includes 38 Balancing Authorities of varying geographic sizes and available generating capacities, none of which compare to the geographic size or the amount of load and generation that exist in either ERCOT or MISO. Some of the Balancing Authorities in the West are unique to the Western Interconnection, such as wind-only Balancing Authorities (Glacier Wind).

A larger geographic area allows a balancing authority to take advantage of the geographic diversity in wind and solar output. The geographic diversity with a larger balancing area aggregates multiple wind plants and permits random weather forecasting errors to cancel out and decrease the overall variability of variable generation. In turn, these can contribute to improved accuracy of forecasting variable generation. A North American Electric Reliability Corporation (NERC) Integration of Variable Generation Task Force paper on wind forecasting found there can be a 30% to 50% reduction in forecasting error from the aggregation and geographic dispersion of wind power, as compared with the error of individual or geographically concentrated wind plants (NERC 2010).

These findings suggest that the accuracy of variable generation forecasting in the Western Interconnection could improve if initiatives such as the Efficient Dispatch Toolkit are implemented.[8] Some of the Balancing Authorities stated that there is no impetus to share or collaborate in variable generation forecasting unless initiatives such as the Efficient Dispatch Toolkit were implemented. Without that, variable generation forecasting accuracy for individual Balancing Authorities in the West will likely lag that of larger balancing areas.

Besides larger balancing areas, ERCOT and MISO have other tools and capabilities that aid in integrating variable energy generation that are not widely utilized in the West. These include sub-hourly scheduling, deep and relatively liquid day-ahead and real-time energy markets, pricing of transmission congestion, and ancillary service markets instead of tariffed rates for ancillary services, as is the case for most of the West.

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[8] The Efficient Dispatch Toolkit is a collection of tools that WECC is investigating to aid the grid integration of wind and solar at the bulk power level. Among other things, the Efficient Dispatch Toolkit being investigated includes either a West-wide or regional Energy Imbalance Market. These tools include aspects of better coordination among the Western Interconnection's 38 Balancing Authorities. For further information, see http://www.wecc.biz/committees/EDT/Pages/default.aspx.

### 4.3.2  Application of Forecast

Most of the 11 Balancing Authorities interviewed for this report use variable generation forecasting for intra-day unit commitment, while a smaller number use variable generation forecasting for both intra-day and forward unit commitment.  ERCOT and MISO use variable generation forecasting for both the forward and intra-day reliability unit commitment to ensure sufficient generation is available to meet electricity demand.[9]

In addition to ERCOT, about half of the Balancing Authorities interviewed for this report use variable generation forecasts for determining the amount of needed operating reserves.  MISO and ERCOT also use variable generation forecasting for transmission congestion management, but only three of the Balancing Authorities in the Western Interconnection (BPA, SCE, and Xcel Energy) use variable generation forecasting for this purpose.

### 4.3.3  Ramp Forecast

ERCOT has a wind ramp forecasting tool that predicts the probability of large ramping events, both region-wide and system-wide.  Three of the Balancing Authorities interviewed for this report are using a ramp forecast. Two of the three began ramp forecasts in late 2011.  As indicated earlier, some companies interviewed for this report thought ramp forecasts should not be a separately provided service; instead they should be part of the regular variable generation forecast.

### 4.3.4  Time Frames Covered by Forecasts

There is variation among the companies about how often forecasts are prepared and how often forecasts are updated.  ERCOT receives an hourly forecast that covers the next 48 hours.  MISO, by comparison, receives five-minute forecasts for each of its CP nodes for the next six hours, updated every five minutes, and hourly updated forecasts beyond the six hours for the next six and one-half days.

Nearly all of the short-term forecasts, for the Balancing Authorities interviewed for this report, covered an hour time frame; although, how often these forecasts are updated varies, from every 10 to 15 minutes to hourly. The short-term forecasts also vary in terms of how far out ahead it goes into the future, from the next hour to a week-ahead (168 hours).  Similar diversity is observed with the medium-term forecasts.  Only a small number of Balancing Authorities interviewed are doing longer-term forecasts of a week-ahead or more.

### 4.3.5  Costs and Benefits of Variable Generation Forecasting

Most Balancing Authorities interviewed for this report pay for the costs of variable generation forecasting, as do ERCOT and MISO. Only AESO and CAISO pass along at least some of the costs of forecasting to variable energy generators, although BPA states that it might propose doing so in a future rate case.

Almost no balancing authority interviewed for this report has done a cost-benefit analysis of variable generation forecasting, and that also applies to ERCOT and MISO.  However, both

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[9] Like most RTOs in the United States, ERCOT and MISO run two security-constrained unit commitment programs for two different purposes.  The day-ahead market is purely financial and used for price certainty and for hedging against the volatility of the real-time market, while the RTO will run the reliability unit commitment program to ensure that enough generating capacity has been committed a day-ahead to serve the load.

ERCOT and MISO are currently involved in the DOE/National Oceanic and Atmospheric Administration Short-Term Wind Forecasting Improvement Project to investigate the reliability and economic benefits that could be gained from reductions in forecast uncertainty.

### 4.3.6  Data Requirements

For the most part, the Balancing Authorities interviewed have data requirements comparable to ERCOT and, to a lesser extent, MISO.  This includes wind speed and direction, temperature, barometric pressure, turbine location, turbine power output, and turbine availability.  There are some exceptions:

- Xcel Energy is the only Balancing Authority engaged in wind power forecasting surveyed that does not require data on temperature or on barometric pressure.  Xcel Energy sometimes receives this information voluntarily.

- BPA and APS receive total wind plant output, not the output of individual turbines.

- The CAISO and BPA receive aggregate wind plant availability rather than the availability of individual wind turbines.

- ERCOT requires all of this information, while MISO provides the latitude and longitude, the hub height, the maximum and historical MW output, and the real-time output to its wind forecasting vendor, but not temperature or barometer data.

Neither ERCOT nor MISO have requirements related to whether the data comes from plant-mounted sensors or from meteorological towers.  In contrast, about half of the Balancing Authorities surveyed have requirements related to met towers, and two additional Balancing Authorities installed met towers to help with data collection.  About half of the Balancing Authorities interviewed require data on turbine outages.  ERCOT requires this information for individual turbines, though MISO does not. However, MISO does request de-rates and outages in its Outage Scheduling tool.

Although some Balancing Authorities reported some difficulties receiving data because of data communication problems, no one (including ERCOT and MISO) has had wind or solar companies withhold data. Neither ERCOT nor MISO has explicit economic penalties or sanctions for failure to provide data.[10]  As noted, AESO may consider penalties in the future, and SCE can reduce power purchase agreement rates for not meeting data requirements.

### 4.3.7  Curtailment

Incorporation of wind curtailment into variable generation forecasting was an early lesson for those using variable generation forecasting.  Most, but not all, of the Balancing Authorities interviewed incorporate curtailment into their variable generation forecasts, although in different ways.  ERCOT sends directives to QSEs to lower their output.  ERCOT also requires wind generators to telemeter their potential net output capability. This provides ERCOT with what a wind resource could be producing if it is being curtailed.  MISO passes curtailment information to the wind forecast vendor and it is used in the composite forecast for the MISO balancing area.

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[10] ERCOT can refer companies that fail to provide data, or fail to provide quality data, to the Texas Reliability Entity (TRE) for action. According to an ERCOT representative, ERCOT has filed at least two complaints with the TRE.

MISO uses either the wind project operator's forecast, or its own, to dispatch and to determine what the wind project could be producing to dispatch upward when the congestion is relieved.

### 4.3.8 Forecast Providers
Both ERCOT and MISO contract with outside wind forecasting companies, as do eight of the Balancing Authorities in the Western Interconnection that were interviewed for this report. Three of the eight, BPA, Glacier Wind, and SCE, contract with more than one forecasting company. Three other Balancing Authorities, Idaho Power, SMUD and Xcel Energy, prepare their forecasts internally.

### 4.3.9 Ensemble Forecasts and Confidence Intervals
Both ERCOT's and MISO's wind forecasting vendors prepare their forecasts with multiple NWP models that are weighted according to past performance or the weather situation, or both. ERCOT uses a probability of exceedence for every hour, set at 50%. MISO does not use either a confidence interval or an exceedence method. Most of the Balancing Authorities surveyed rely on ensemble forecasts coming from third party providers (AESO, APS, CAISO, Turlock), from multiple forecast providers (BPA, SCE), or conducted internally (Xcel Energy). AESO, Glacier Wind, SCE, and Xcel Energy are using confidence intervals and APS, CAISO, and Idaho Power are considering using confidence intervals. BPA uses varying maximum and minimum intervals.

## 5 Summary

Variable generation forecasting is regarded by many as an important tool towards successfully integrating variable generation technologies. This report surveyed Balancing Authorities in the Western Interconnection on their implementation of variable generation forecasting, the lessons learned to date, and recommendations they would offer to other Balancing Authorities considering whether to implement variable generation forecasting. Eleven Balancing Authorities in the Western Interconnection were interviewed.[11] These were selected based on responses they gave to an earlier wind forecasting survey conducted by WECC, and by the authors' knowledge of other Balancing Authorities in the West that were involved with variable generation forecasting. Because this report was prepared at the request of the SPSC, this summary will include some suggested actions for states to consider.

Our survey found that variable generation forecasting is at an early implementation stage in the West, with 8 of the 11 Balancing Authorities interviewed beginning forecasting in 2008 or later. As such, Balancing Authorities in the West are gaining experience with variable generation forecasting, and it is likely that they will make changes and improvements as they gain more experience with variable generation forecasting.

While most of the existing wind capacity in the West appears to be included in variable generation forecasting currently, it appears that less than one-half of Balancing Authorities in the West are currently utilizing variable generation forecasting, since many do not currently have enough variable generation to justify forecasting. This suggests that should wind (and

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[11] Readers are reminded that Southern California Edison (SCE) is not a balancing authority per se—the CAISO is the balancing authority for most of California. However, SCE was one of the first, if not the first, electric utilities in the United States to employ wind forecasting, and for that reason, SCE was chosen to be interviewed.

increasingly solar) capacity be added, more Balancing Authorities in the West will engage in variable generation forecasting, either directly or with a third party vendor. States may wish to consider asking whether Balancing Authorities in their State are utilizing variable energy forecasting, and if so, what plans may be in place to add to or to improve variable generation forecasts in the future should variable generation increase. If not, states may wish to ask whether there are plans to adopt variable generation forecasting in the future, particularly if new wind or solar generating capacity is expected.

Several large-scale variable generation integration studies have determined that incorporating today's state-of-the-art variable generation forecasts into advance (e.g., day-ahead) scheduling and dispatching of generation plants can reduce total system operating costs through decreased fuel consumption, operation and maintenance costs, and more efficient plant dispatch overall. Most of the Balancing Authorities interviewed for this report use variable generation forecasts for intra-day unit commitment, not for forward unit commitment. By comparison, ERCOT and MISO use variable generation forecasts for determining their forward unit commitment schedules. States may want to consider asking their Balancing Authorities whether there are plans to incorporate variable generation forecasts into forward unit commitment schedules, such as day-ahead unit commitment schedules, to ensure that adequate generation resources are prepared to be online when they require significant notification time to start up operations. Transitioning to incorporating variable generation forecasts into forward unit commitment schedules will help in making generation scheduling decisions more efficient.

Further evidence that variable generation forecasting is at an early stage in the West is the diversity of approaches Balancing Authorities took towards defining what variable generation forecasts they wanted (such as short-term, medium-term, long-term, and ramp forecasts), how these forecasts are prepared and how different forecasts are defined (i.e., short-term versus mid-term forecasts), as indicated in Table 4. In essence, there is no agreement on what defines or what comprises certain types of forecasts such as short-term or medium-term forecasts. Some of this is to be expected, not only because of the early stage of variable generation forecasting in the West but also because previous research has found that no single approach works best for all times, conditions, or locations. Put another way, some customization is involved in creating variable generation forecasts to meet local conditions and the needs of the balancing authority. That said, some convergence of definitions and methods is likely over time as Balancing Authorities gain more experience with variable generation forecasting and "best practices" become more defined and understood. For Balancing Authorities with variable generation forecasting systems, states may wish to ask how their variable generation forecasting systems compare with other variable generation forecasting systems in the United States, both inside and outside of the Western Interconnection.

Only a small number of Balancing Authorities interviewed for this report are utilizing ramp forecasts, also in part because of the early stage of variable generation forecasting in the West. There was also some skepticism expressed by some of the Balancing Authorities interviewed as to the need for a separate ramp forecast, and that ramp forecasts should be part of the variable generation forecast that is already provided. The time periods for defining a ramp is an important criterion, with longer time periods (e.g., 20 minutes versus 60 minutes) generally resulting in more ramps. States could consider asking their Balancing Authorities how they define variable generation ramps; whether variable generation ramps are of concern, either now

or in the future; whether their existing variable generation forecasting system, if applicable, is adequate at predicting ramps in variable generation; or whether they are considering adopting a separate variable generation ramp forecast.

Most of the Balancing Authorities interviewed stated that it takes time to implement a variable generation forecasting system and recommended that other Balancing Authorities start early with variable generation forecasting. A few Balancing Authorities reported some technical problems in communicating with, and receiving data from, variable generation projects. Some noted that older wind plants generally do not have the communications infrastructure to provide data. Balancing Authorities interviewed also have tended to ask for data from either plant-mounted sensors or from metrological towers as they gained some experience with variable generation forecasting.

Few of the Balancing Authorities interviewed for this report have conducted detailed cost-benefit studies of variable generation forecasting, and those that did employed very different methodologies. Some questioned whether such a study is needed, saying the costs of forecasting are small compared to the benefits (e.g., more knowledge of projected variable generation output and increased system readiness) and variable generation forecasting has to be seen as a necessity with higher levels of variable generation. States may wish to question their Balancing Authorities on whether they have considered assessing the costs and benefits of variable generation forecasting. However, states should also recognize that variable generation forecasting is widely seen as necessary to maintaining grid reliability at higher levels of variable generation capacity.

Among the Balancing Authorities interviewed, there was support for more coordinated variable generation forecasts among multiple Balancing Authorities, but most expressed skepticism that this will happen without a requirement or some sort of forcing function. No one who was interviewed is currently sharing forecasts outside their own balancing authority, although SCE and CAISO share forecasts by virtue of SCE being in the CAISO's Participating Intermittent Resource Program. States may wish to ask Balancing Authorities whether there would be value in sharing or coordinating variable generation forecasts with other Balancing Authorities.

Variable generation forecasting in the Western Interconnection was also compared with forecasting in ERCOT and in MISO. The most significant difference is the larger size of the ERCOT and MISO balancing areas as compared to Balancing Authorities in the West. The larger geographic areas that ERCOT and MISO encompass take advantage of geographic diversity in wind and solar output that permits random weather forecasting errors to cancel out and decreases the overall variability of wind and solar generation, leading to a corresponding improvement in forecasting accuracy. This suggests variable generation forecasting accuracy in the West could improve if initiatives to better coordinate across BAs, such as some or all of the Efficient Dispatch Toolkit, are adopted.

That said, ERCOT and MISO have other mechanisms in place that, while not solely intended to integrate variable energy generation, make it easier to do so. These include sub-hourly scheduling, liquid day-ahead and real-time energy markets, pricing of transmission congestion, and ancillary service markets instead of tariffed rates, as is the case with most Balancing Authorities in the West. It also suggests that while variable generation forecasting is vital at

higher levels of variable generation, it should complement other methods in the West for integrating variable energy generation.  Other mechanisms for integrating variable energy generation will be needed with increased deployment of variable generation.

# 6 For Additional Reading

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# Appendix A: Glossary

**Confidence interval:** The probability that a value will fall between an upper and lower bound of a probability distribution.

**Curtailment:** Generation that could be online but is directed to run at a lower level or dispatched off-line to alleviate grid congestion or to maintain reliability.

**Day-ahead forecast:** See 'Next-day' forecast.

**Down reserves:** Generation resources that are capable of being dispatched to a lower level (or load which can be increased) in response to a directive from a system operator.

**Ensemble forecast:** A method of forecasting that uses multiple weather forecast models and/or a weather forecast model with a range of perturbed input conditions, based on the uncertainty range of the measurements.

**Forecast bias:** The amount that a forecast that is consistently skewed towards under- or over-forecasting.

**Load:** The aggregate demand for electricity consumed by devices connected to the electric grid; sometimes also used to include the customers who own and operate those devices.

**Long-term forecast:** While long-term forecast has different meanings to different people, it generally refers to any forecast that runs out beyond week-ahead.

**Mean absolute error (MAE):** Standard statistical analysis tool used to evaluate the success of wind forecasting systems in predicting actual wind power generation. MAE takes the simple average of the absolute values of the individual wind forecast errors.

**Medium-term forecast:** See 'Next-day' forecast.

**Model Output Statistics:** Statistical prediction of observed weather parameters using Numerical Weather Prediction model output variables as input.

**Next-day forecast:** Also referred to as day-ahead, or medium-term, forecast. The term "next-day forecast" (as contrasted with the term 'short-term' or 'next-hour' forecast) is traditionally used in the wind power forecasting sense to define a forecast that runs out over the coming days (such as for the next five days). This forecast may be presented with hourly time steps or can be shown with shorter time steps.

**Numerical Weather Prediction (NWP):** A computer forecast or prediction based on equations governing the motions and the forces affecting the atmosphere. The equations are initialized on specified weather or climate conditions at a certain place and time.

**Outage:** A condition which occurs when a generation or transmission facility or element is out of service and not able to generate or transmit power.

**Persistence forecast:** Forecast that assumes the current value will be the same at a future point in time (e.g., 15 minutes-ahead, hour-ahead, etc).

**Probabilistic forecast:** A forecast that shows not only the expected value, but also a measure of the probability distribution or confidence around the value. This distribution may be obtained from various indicators including the degree of agreement between multiple weather models (see ensemble forecast), historical performance under similar conditions, the location on the turbine power curve for the predicted wind speeds, and other such considerations.

**Ramp forecasting:** A "wind ramp" is a relatively rapid and sustained change in wind power output within a specified time period. The exact definition may vary based on the size, situation, and flexibility of the system. A "wind ramp forecasting system" is one that is tuned to identify the risk and potential ramp rate from such an event. This tuning for ramp events could be done as part of a wind power forecasting system, separate ramp forecasts that are distinct from the wind power forecasts, or various combinations thereof.

**Rolling training sample:** Refers to one of a number of Model Output Statistic techniques that uses only a recent history, typically a few weeks, as the training set with a continual recalculation of the Model Output Statistic equations.

**Root mean square error (RMSE):** Standard statistical analysis tool used to evaluate the success of wind forecasting systems in predicting actual wind power generation. RMSE involves obtaining the total square error first, then dividing by the total number of individual errors, and then finally taking the square root. RMSE is more sensitive than Mean Absolute Error (MAE) to outliers, giving a high weight to large errors since they are squared prior to being averaged. The RMSE will always be equal to or greater than the MAE, with a large difference between them signaling a high variance in the individual sample errors.

**Short-term forecast:** While short-term forecasting means different things to different people, when used in the wind power forecasting sense, the terms "hour-ahead" or "short term" generally refer to forecasts for the time span from now through the coming three to six hours. This forecast is often updated frequently and presented with frequent time steps (such as every ten minutes).

**Solar insolation:** A measure of solar radiation energy received on a given surface area at a given time, generally expressed in $Wh/m^2$ (watt-hours per square meter) or, in the case of photovoltaics, kWh/(kWp•yr) (kilowatt hours per year per kilowatt peak rating).

**Supervisory control and data acquisition (SCADA):** Specialized computer systems that monitor and control industrial processes, including the operation of components of the electric grid, by gathering and analyzing sensor data in near real time.

**Up reserves:** Generation resources that are capable of being dispatched to a higher level (or load which can be decreased) in response to a directive from a system operator.

**Weather Situational Awareness:** Any of a large range of technologies intended to convey near-real-time weather information to an operator or user in an actionable form. For example, general weather information could be made more "actionable" for an operator by visually or numerically converting the information into warnings and alerts of impacts that are more directly useful to the operator or user.

# Appendix B: Variable Generation Forecasting Survey

**Forecast Information**

1. Please tell us about your variable generation forecasting system. When did you start forecasting, and what were the reasons for doing so? Do you forecast for wind only, or for wind and solar?

2. What time frames are covered by the forecast?

   ____ Short-term forecasts. How often are the forecasts prepared and updated?
   ____ Medium-term forecasts. How often are the forecasts prepared and updated?
   ____ Long-term forecasts. How often are the forecasts prepared and updated?
   ____ Ramp forecasts. If so, how often are the forecasts prepared and updated? If not, do you expect to implement a ramp forecast in the future?
   ____ Other

3. What is the scope of the variable generation forecast?

   ____ Individual wind or solar plant
   ____ Individual utility or balancing area
   ____ Commercial pricing node
   ____ Multiple utilities or balancing areas
   ____ Region
   ____ Other

4. What type of forecasts are you preparing or using?

   ___ Persistence (if so, please provide details on the timing of the look-ahead period)
   ___ Numerical Weather Prediction Model
   ___ Statistical
   ___ Weather Situational Forecasts
   ___ Ramp Forecasts
   ___ Other

**Use of Forecasting**

5. Please describe how you use your variable generation forecasts:

        \_\_\_     Unit commitment  (Day-ahead, week-ahead, etc.)
        \_\_\_     Intra-day unit commitment?
        \_\_\_     Transmission congestion management
        \_\_\_     Planning reserves (if so, on what time frame?  Day-ahead?  Months or Years ahead?)
        \_\_\_     Management of hydro or gas storage
        \_\_\_     Planning generation or transmission scheduled outages
        \_\_\_     Other

6. Is the variable generation forecast integrated into the Energy Management System in the control room?  If not, why?  Do you anticipate taking that step in the future?

**Costs and Benefits of Variable Generation Forecasting**

7. How much did your variable generation forecast system cost?  Are variable generators responsible for some or all of the costs of the variable generation forecasting system, and if so, how?

8. Has your company estimated the costs and benefits of using variable generation forecasting?  If yes, please describe how the costs and benefits were determined, and were the estimated prepared before or after the company implemented variable generation forecasting? Please also provide a copy of the estimates, if they are available.  Has your company estimated the reduction of system costs or the reduced amount of reserves from the use of variable generation forecasting?

**Future of Variable Generation Forecasting in the West**

9. What are the strengths and weaknesses of variable generation forecasting?  What would be done differently if you were to begin variable generation forecasting, knowing what you know now?  What advice would you give other balancing areas that are thinking about implementing a variable generation forecasting system?

10. Has your company's use of variable generation forecasting changed or evolved over time?  If so, please describe.  What changes do you anticipate making to your variable generation forecasting system in the future, if any?

11. What should the West do regarding variable generation forecasting? Do you see any benefit in coordinated variable generation forecasts with multiple balancing areas? Have you consider jointly doing variable generation forecasts with other Balancing Authorities, or participating in a sub-regional or regional variable generation forecast?

**Data Collection**

12. Do you require wind or solar generators to provide data for your forecast? If so, what? See below for examples.

    ___ Wind speed and direction
    ___ Temperature
    ___ Barometric pressure
    ___ Turbine location in latitude and longitude
    ___ Turbine power output
    ___ Turbine availability
    ___ Turbine outage
    ___ Wind turbine power curve
    ___ Solar insolation
    ___ Other

13. If you require variable generators to provide data, are there requirements (or a preference) that it come from metrological towers as opposed to plant-mounted sensors? Are there other requirements on where the data is sourced from, such as coming from a minimum of metrological towers be used?

14. Are you getting the data you need from variable energy generators? Are there sanctions or penalties in place if the data is not provided?

**Miscellaneous Questions**

15. Do you contract with an outside company to provide the forecast or is it done in-house? If an outside company is used, who is it? Is there a statement of work you can provide (without commercially sensitive information) that describes the responsibilities, expectations, and any performance metrics or targets of the variable generation forecasting vendor?

16. Do you or your forecasting vendor use a probabilistic approach to forecasting? Do you use a confidence interval with your variable generation forecast, and if so, what confidence interval do you use? Do you utilize ensemble variable generation forecasting with multiple vendors, or a vendor that prepares several different forecasts based on different model inputs, weather fronts, etc.?

17. Does your variable generation forecast factor in production curtailments or turbine outages? If so, please describe that process of incorporating production curtailments or turbine outages into the variable generation forecast.


18. How do you assess the accuracy of your variable generation forecast (i.e., through Mean Absolute Error, Root Mean Square Error, etc.)? What error rates have been observed? Have these improved or worsened over time?

# Appendix C: Original Variable Generation Forecasting Survey

The survey in Appendix B is an edited version of what was originally created by the Western Interstate Energy Board.  The full survey is provided as reference for future variable generation forecasting surveys, should such surveys be undertaken.

**Data Collection**

1.  Do you collect and maintain data gathered at wind and solar plants that supply power to your utility?

     No:  Why not?_____.  (Proceed to question _____)

     a.  Do you require data from renewable plants to be delivered to us as a requirement of our contracts with suppliers?

     b.  What does the data collected include? (check all that apply):
         □ Meteorological information (wind speed, direction, temp, pressure, humidity),
         □ Power output,
         □ Wind turbine outage/availability information (including icing issues), and
         □ Plant curtailment information (deployment instructions in MW and estimated MW output available if a current curtailment is lifted).
         □ Other _____

     c.  How long do you maintain the data?
         □ Weeks
         □ Months
         □ Years

     d.  What is the format of the data?

     e.  Did collecting this data require confidentiality provisions to be in place?

**Forecasting Information**

2.  Do you collect forecast information for wind and/or solar?

     No:  Why not? _____(Proceed to question ____)

     a.  What is the scope of the forecast?
         □ Plant-by-plant forecast
         □ Utility-wide forecast
         □ Multi-utility or BA level forecast
         □ Regional perspective
         □ Other_____

     b.  What is the timeframe of the forecast?
         □ Next ten minutes
         □ Next hour
         □ Next day
         □ Ten minute power values for next 6 or so hours

3.  What type of forecast do you employ?
         □ Persistence (last hour predicts the next hour)
                 What look-ahead period is covered?_____
         □ Numerical weather prediction (physics based) model

- □ Statistical model (Incorporates artificial learning system (learns from experience)
- □ Multiple forecasts for different purposes (list)
- □ Weather situational forecast (Extreme events: lightning, high wind warnings, ramp risk forecast)
- □ Nodal Injection Forecast
- □ Ensemble forecasting techniques[12]

1. Is the forecast a combined "load net wind" forecast?
2.

## Use of Forecast

<u>In operations</u>

3. Is the forecast provided used by operators?

   No: why not? _____ (proceed to question ____)

   a. How often do operators use the forecast?
      - □ Hourly
      - □ Several times a day
      - □ Daily
      - □ Weekly
      - □ Monthly

   b. How do operators use the forecast? _____
      i. Is the forecast employed in the operating timeframe (next 48 hours)?
         No: Why not? _____ (proceed to question _____)
      ii. How is it used?
         - □ To improve scheduling
         - □ Hour ahead scheduling
         - □ Less-than-hour-ahead scheduling and dispatch
         - □ To improve system control
      iii. Is the forecast integrated into the Energy Management System environment in the control room?

<u>In unit commitment</u>

4. Do you use your forecast for unit commitment decisions in the next days and weeks?
5. Does the forecast inform unit commitment algorithms by, among other things, helping to determine the reliability of unit commitment?

   a. Is the forecast used to inform changes to the intra-day unit commitment stack during low load periods?

<u>In planning</u>

6. Is the forecast used for any of the following? (check all that apply)
   - □ Planning curtailments
   - □ Planning storage use

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[12] An ensemble forecast uses multiple weather forecasts, each based on somewhat different models or initial conditions, and the level of agreement between the multiple forecasts can be an indicator of the forecast confidence.

       □ Reduction of thermal regulating plant costs

       □ Reduction of system costs

7. Do you use your forecast for planning transmission outages for maintenance or repairs over the next days and weeks?

8. Do you use your forecast for planning reserves in the next months and years?

9. Do you use your forecast for planning system additions and retrofits with adequate flexibility for the next months and years?

<u>In determining ramp needs</u>

10. Is your forecast used to anticipate ramp needs?

     No: Why not? _____(Proceed to question_____)

    b. What information do you gain from your forecasts in terms of up/down ramp needs?

       i. Up ramp:

         □ Cold front passage

         □ Thunderstorm outflows

         □ Rapid low pressure intensification

         □ Mountain wave events

         □ Flow channeling (valley wind tunnel)

         □ Other_____

       ii. Down ramps:

         □ Turbines reaching cut out speeds

         □ Clouds over solar facilities

         □ Icing events

         □ Near-surface boundary layer stabilization at sunset/nightfall

         □ Relaxation of pressure gradient as high pressure moves in following cold front passage

         □ Pressure changes following passage of thunderstorm complexes

         □ Decrease in wind speed as a warm front passes

         □ Other_____

11. Do you use your forecast for planning to acquire generation with ramping capabilities for the next months and years?

<u>Generation, fuel purchases and deliveries</u>

12. Do you use your forecast for scheduling fuel purchases and deliveries for the next days and weeks?

13. Do you use your forecast for planning minimum generation requirements over the next days and weeks?

<u>Transmission congestion</u>

14. Used in transmission congestion management process?

<u>Changes in use of forecasting</u>

15. How has the use of forecasts by operators changed?

    a. What changes in use of forecasts are coming in the future?

    b. Is there a plan for continuous improvement in forecasting and use?

## Operator knowledge of forecasting

16. How much training have operators had about forecasting?
17. How much experience have operators had with their current forecasting system?
18. Has forecasting led to more efficient dispatch, saved fuel and reduced O&M charges?
19. Do operators have working knowledge of best forecasting practices
    a. From what sources? (check all that apply)
       □ Utility Wind Integration Group (UWIG)
       □ NREL, DOE, WECC, other industry sources
       □ European experiences
       □ Texas ERCOT or other U.S. wind operations
       □ Other _____

## Forecast Accuracy

20. Do operators find the forecasts provided to be accurate?
    a. How do operators assess forecast accuracy?
    b. Have operators observed any forecast accuracy improvements?
       i. What were the reasons forecasts improved?
    c. What error rates have you observed (Mean Absolute Error, Root Mean Square Error)?

## Forecast Provider

21. Do you have a contract with a supplier to provide a forecast for operations?
    a. Do you contract with more than one provider to address various conditions and to inform various kinds of decisions?
22. What does your forecasting operation cost?

## Central and Local Forecasting

23. Are forecasts for loads, gas operations, and variable resources provided together?
    If separately provided, why?_____
24. Is a mixture of centralized forecasting and local forecasting in use?
25. Would centralized regional forecasting provide a big picture synthesis and balancing area level control the overall picture?
26. Would regional forecasting help operators understand impacts of widely dispersed wind and solar projects?
27. What steps has your company taken to encourage improvements and competition in wind and solar power forecasting?
28. Has your company moved toward ensembles of forecasts and forecasting providers?