Wind Power Forecasting Pilot Project

Progress Review

28 February 2008

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Executive Summary

Background

The large-scale development of wind power facilities presents a number of opportunities and challenges for power system operation and the AESO. Introducing significant amounts of wind generation to the power system poses a number of operational challenges due to the intermittent nature and characteristics of wind power. In addition, few wholesale electricity market designs specifically recognize the effects of wind power so new rules, practices must be developed and/or existing rules must consider and accommodate the characteristics of wind generation.

The AESO has been working with industry stakeholders on wind integration issues since 2004 and introduced the Market and Operational Framework (MOF) for wind power integration in the spring of 2007. The MOF outlines how wind power will be integrated into the Alberta electricity market in a fair, efficient and reliable manner.

The basic premise of the MOF is if the AESO receives a reasonable forecast of wind power generation, then the System Operator can establish a plan to accommodate the forecast wind energy by using the following resources/tools:

- The Energy Market Merit Order[1];
- Regulating Reserves;
- Supply following services;
- Wind generation power management.

In anticipation of the role of wind power forecasting in large-scale wind power development, the AESO, in conjunction with the Alberta Department of Energy, the Alberta Energy Research Institute, CanWEA and an Industry Work Group initiated a wind power forecasting pilot project in the summer of 2006. The project consists of trialing three different forecasting methods and vendors over the course of a year to try to determine suitable methods and approaches for wind power forecasting in Alberta. The third quarter of forecast delivery and second quarter review cycle has been completed, and this paper provides the project progress review.

[1] **"energy market merit order"** means the list of all valid offers and bids for a settlement interval sorted in order of offer and bid price blocks.

Progress Review

The wind power forecasting pilot project is on track to meet the objectives outlined at the outset of the project. The project continues to provide a tremendous learning experience for all involved including the forecasters, the independent quantitative analysis provider, the data provider, the AESO and the Industry Work Group. The project has facilitated frequent opportunities for open and candid discussion about the success and challenges of wind power forecasting in Alberta. As the project progressed from design, to implementation, to execution, it became evident that the work being done was ground breaking, not only in Alberta, but the project has also attracted world wide attention.

A leading indicator of project success will be the ability to communicate and capture all the lessons learned from all participants in the study in order to identify the best way forward for wind power forecasting. We have employed several methods to draw out the lessons, share lessons amongst team members and to communicate findings to stakeholders.

The first method being used to communicate the capabilities of wind power forecasting is the independent quantitative analysis being conducted by ORTECH Power (based in Ontario). ORTECH has completed two quarterly reports displaying several evaluation metrics looking at the capabilities of wind power forecasting in different projected hours, in different geographical regions, at different wind speeds, and many more. The key finding from the ORTECH analysis to date is that the current metrics used to evaluate wind power forecasts may be useful to marketers and wind developers, but may not be the most appropriate metric from a system operator’s perspective. This is likely due to the fact that wind power forecasting has not been used widely in system operations to date. A system operator’s needs and concerns are different than those of a wind developer or marketer. The AESO and the Industry Work Group continue to work with ORTECH to ensure the right metrics are utilized in order to answer the right questions which in turn will position system operators for success.

However, this key finding from the ORTECH reports has led to examining other ways to evaluate the performance of wind power forecasts. The second method being used is the special event analysis conducted after wind power or forecast events occur that are deemed to be of concern to system operations. Each event is broken down with forecaster and AESO comments as to why the event unfolded, what could have been done to better capture the event from a forecasting perspective if missed, and what it would have meant to the AESO.

This analysis has proved to be a huge success. It has provided an opportunity for the forecasters to explain the success or challenges of their methods, educate the readers on the weather pattern that made the event interesting, and capture the lessons learned for future compilation. The key findings from this analysis so far are:

- Because extreme events can be completely missed by forecasts, system operations must be prepared to handle this type of error.

- Phase error or timing error is prevalent and must be understood.
- Models tuned for good average statistics may not capture extreme events very well.
- The uncertainty associated with a forecast may be as important as the forecast itself.
- Having situational awareness of a possible extreme weather condition relating to wind power may be as helpful as a time series forecast of wind power.

The third method being used is the Wind Power Market and Operational weekly reports posted to the AESO website since the end of November 2007. In each report, there is a section displaying a forecasting event of interest from that week. An event could be a well forecasted ramp up or down of wind, a missed forecast of the same, a diversified forecast between the three vendors, or anything that might be of interest to market participants. These reports allow participants to follow the performance of the forecasts and to understand their capabilities. They also provide a valuable signal to the market that ramping resources are required to accommodate wind generation.

The fourth method will be the forecasters' final reports. The AESO and Industry Work Group are eagerly awaiting these final reports, which will include a summary of each forecaster's experience in forecasting in Alberta during the previous year. This will include all of the forecaster's lessons learned as well as recommendations regarding how they feel forecasting should be implemented in Alberta. We received a preliminary glimpse into what the forecasters feel are the areas that need improvement when they submitted their project wish lists. In these summaries, the forecasters outlined the contributing factors to some of the forecast error and their suggested solutions. Some of the key suggestions are:

- More representative wind farm anemometer data. The anemometer needs to be strategically located and not subject to wake losses from turbines
- Accurate observed availability data of turbines and facilities
- Sensors that can measure vertical wind shear and stability in vicinity of the wind farms
- Offsite towers that can provide information for short-term forecasts
- 6-hr forecasts cycles with longer forecast periods from Environment Canada's NWP models
- Higher resolution objective analysis in time and space from Environment Canada (Canadian Meteorological Center)

The fifth method includes the analysis conducted by the AESO around ramping events. The AESO has developed a new methodology to examine the delivered forecasts and evaluate how well they capture ramping events. The AESO analysis attempts to quantify phase (i.e. timing) error as well as amplitude error. This analysis is still being explored and is introduced in this review for discussion. The analysis is expected to help industry to further understand wind power forecasting capabilities around ramping events and possibly lead to a definition of requirements around forecast performance.

Finally, the AESO has been in discussions with Environment Canada to understand the strengths and weaknesses of the underlying national weather forecasts. Forecaster comments have identified these forecasts as being a key contributor to wind power forecast error in their comments regarding special event analysis and the wish lists. These discussions led to the notion that while error exists in the underlying National Numerical Weather Prediction (NWP) models, by using a local meteorologist's assessment of the forecasts and the current unfolding weather pattern, significant improvement can be made to phase error and uncertainty embedded in the forecasts. The AESO intends to run a controlled experiment during the pilot project to validate the benefit of getting a daily assessment of the forecasts from a meteorologist.

ORTECH Power's third quarter results are expected in mid March, 2008. The final reports from the forecasters and ORTECH are expected at the end of May and June, 2008 respectively. The Industry Work Group recommendation to the AESO is expected at the end of August 2008. The project is on track to meet the terms outlined within the contracts and grant agreements.

At this stage of the project there is a much better understanding of the capabilities of wind power forecasting, the techniques behind wind power forecasting, and how wind power forecasting may be used in Alberta. The methods being used to perform evaluation will continue to be optimized in order to extract the greatest value.

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1.0 Introduction

The large-scale development of wind power facilities presents a number of opportunities and challenges for power system operation and the AESO. Introducing significant amounts of wind generation to the power system poses a number of operational challenges due to the intermittent nature and characteristics of wind power. In addition, few wholesale electricity market designs specifically recognize the effects of wind power so new rules, practices must be developed and/or existing rules must consider and accommodate the characteristics of wind generation.

The AESO has been working with industry stakeholders on wind integration issues since 2004. This involved the issuance of the Wind Poweer Facility Technical Requirements in November 2004.[2] In those requirements, the AESO delayed its decision on the operational needs until wind variability and its impacts were better understood. The AESO System Impact studies[3] provided as assessment of the operational impacts and direction on which mitigating measures should be pursued. Wind power forecasting was one of the most effective mitigating measures studied.

In 2006, CanWEA and Garrad Hassan conducted a study on wind power forecasting.[4] The study examined how wind power forecasting is being conducted and used in jursitictions around the globe. One of the key findings of the study was that a forecasting method that works well in one area, may not work well in others due to geographical differences. Another key recommendation was that there should be a pilot period of forecasting in an area to determine how best to forecast before implementing into operations.

In the spring of 2007, the AESO introduced the Market and Operational Framework (MOF)[5] for wind power integration. The MOF outlines how wind power will be integrated into the Alberta electricity market in a fair, efficient and reliable manner. The basic premise of the MOF is if the AESO receives a reasonable forecast of wind power generation, then the System Operator can establish a plan to accommodate the forecast wind energy by using the following resources/tools:

- The energy market merit order;
- Regulating Reserves;
- Load/Supply following services;
- Wind generation power management.

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[2] http://www.aeso.ca/downloads/Wind_Power_Facility_Technical_Requirements_Revision0_signatures_JRF.pdf
[3] http://www.aeso.ca/gridoperations/13843.html
[4] Short-term Wind Energy Forecasting: Technology and Policy, Garrad Hassan, 2 May 2006
[5] http://www.aeso.ca/downloads/Wind_Framework_7March07.pdf

In anticipation of the important role of wind power forecasting, the AESO, in conjunction with the Alberta Department of Energy, the Alberta Energy Research Institute and CanWEA, initiated the wind power forecasting pilot project in the summer of 2006. This involved the stand up of an industry Work Group with representatives from the wind development community, Environment Canada, conventional generator owners, and government. The Work Group role is to advise the AESO throughout the project to ensure it meets its objectives.

2.0 Purpose

The purpose of the wind power forecasting pilot project is:

- To evaluate different forecasting methods in order to find the most effective means to forecast wind power in Alberta;
- To leverage the experience of other jurisdictions globally;
- To educate Alberta's power industry on wind power forecasting techniques and capabilities;
- To recommend wind power forecasting requirements to be implemented in Alberta.

At the end of the project, the Work Group will submit recommendations to the AESO regarding how wind power forecasting will be implemented into Alberta and what should the technical requirements be to enable wind power forecasting. The information from the pilot project will feed into the other AESO wind integration work streams of wind power management, AS forecasting, and system operator tools.

3.0 Pilot Project Design

The project consists of trialing three different forecasting methods and vendors with an assortment of backgrounds and jurisdictional experiences. The forecasters selected via a RPF process were AWS Truewind from the US, WEPROG from Denmark, and energy & meteo systems from Germany.[6]

The forecasters provide forecasts for 12 different wind power facilities (7 existing facilities and 5 future facilities) spread out across southern Alberta in four regions defined by similar wind patterns (see figure 1). A forecast is provided each hour, predicting the next 48 hours for an entire year covering all seasons. The forecasts include predicted wind speeds, wind power, and ramp rates.

Genivar (formally Phoenix Engineering), collects all the meteorological data and observed power data and sends to the forecasters. Genivar also acts as the data hub

[6] http://www.aeso.ca/gridoperations/13864.html

receiving all forecasts and distributing them to the AESO and to ORTECH Power. ORTECH Power was selected via a RFP process to provide an independent quantitative analysis of the forecasting results.

See appendix I for a detailed description of design, input datasets, output datasets, schedule, ORTECH analysis and updated schedule.

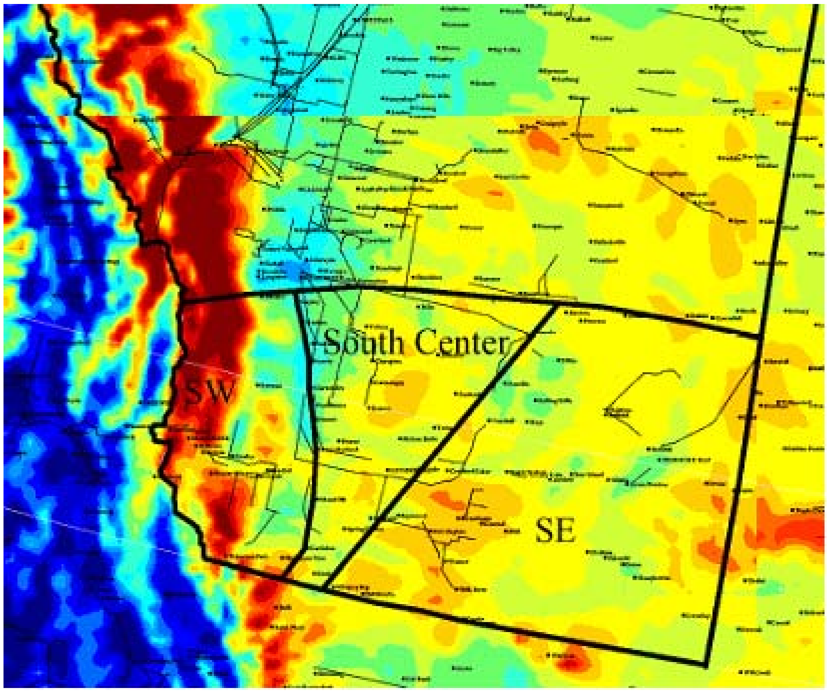

Figure 1 – Regions

4.0 Progress Review

The wind power forecasting pilot project is well on the path to meet the objectives outlined at the outset of the project. Chief among those objectives is to educate the industry on wind power forecasting techniques and capabilities. Once industry understands the present nature of wind power forecasting, how it will be implemented into system operations and market rules will be determined. This includes outlining the technical requirements needed to be met by market participants in order to facilitate wind power forecasting.

The project has been a tremendous learning experience for all involved including the forecasters, the independent quantitative analysis provider, the data provider, the AESO and the Industry Work Group. The project has facilitated frequent opportunities for open and candid discussion about the success and challenges of wind power forecasting in Alberta. As the project progressed from design, to implementation, to execution, it became evident that this was ground breaking in many respects. A key indicator of success of the project will be the ability to communicate and capture all the lessons learned from all participants in order to identify the best way forward for wind power forecasting.

We have employed several means being utilized to draw out the lessons, share lessons amongst team members and to communicate findings to stakeholders. Each of these methods has different benefits associated, some of which will be fully appreciated at the end of the project. These methods and the findings from each method achieved to date will be discussed in detail in section 4.0. They are:

- The ORTECH Power independent quantitative analysis;
- The special event analysis;
- The Weekly Market and Operational Wind Power Reports;
- The forecaster reports;
- The AESO Analysis;
- The AESO/Environment Canada collaboration.

ORTECH Power's third quarter results are expected in mid March, 2008. The final reports from the forecasters and ORTECH are expected at the end of May and June, 2008 respectively. The industry Work Group recommendation to the AESO is expected at the end of August 2008. The project is on track to meet the terms outlined within the contracts and grant agreements.

4.1 The ORTECH Power Independent Quantitative Analysis

ORTECH Power was selected to provide an independent quantitative analysis of the forecasts. The industry Work Group requested that an unbiased third party be selected to provide an impartial analysis. ORTECH Power has completed the first two quarterly reports[7] showing many metrics outlining the performance of the forecasts. After completing the review of the second quarter report, there is a concern between the forecasters, the AESO, the Work Group participants and ORTECH itself, that the ORTECH results will not contribute to the project objectives being met. The reason for this is that the metrics chosen may not be appropriate from a system operator's perspective. The root cause discovered is that the standard measures of evaluating forecast error, such as mean absolute error (MAE) and root mean square error (RMSE), may not provide the required information needed for a system operator. As such, the AESO and industry Work Group are working with ORTECH to find the best metrics to use in Alberta. This has been a worthwhile lesson to learn given at the outset of the project it could not be envisioned whether or not certain metrics would be useful. The results needed to be studied and reviewed before this assessment could be made.

[7] Wind Power Forecasting Pilot Project Part B: The Quantitative Analysis Revised First Quarterly Report, 19 October 2007; Wind Power Forecasting Pilot Project Part B: The Quantitative Analysis Second Quarter Progress Report, 28 January 2008.

The key findings or confirmations from the ORTECH analysis to date are:

- In the short term (T-2 to real time) the model forecasts (delivered from the forecasters) and persistence forecast perform similarly on average. In the longer terms, the model forecasts perform better than persistence. This is important to understand when deciding in what timeframe model forecasts will be implemented in Alberta.

- The dispersion component of RMSE represents the phase or timing error of the forecast. The ORTECH analysis breaks out the dispersion component of the RMSE, and this component is the largest contribute to RMSE in Alberta. The finding is that phase error is large and its impacts must be understood in determining how to implement with phase error present.

- Using the current standard metrics, there is not a distinguishable leader in forecast performance by vendor or by region.

4.2 The Special Event Analysis

The AESO receives a forecast for the aggregate power of the existing facilities every hour predicting the next 48 hours. With this forecast, the AESO started performing special analysis on events of interest to system operators. These events revolve around fast ramps up or down of wind power or wind power forecasts. The system impact studies identified that wind ramping at high rates poses the largest challenges to system operations. If it correlates with a load ramp, wind will be beneficial to system operations, but if not, it may be a challenge to match the net ramp rate with the energy market and ancillary services available. This event analysis examines wind ramps that were either forecasted or missed in forecast in order to understand what constitutes a good forecast of a ramp, what constitutes a missed forecast, why a forecast was a success or challenge to accurately predict, what could have been done to better capture the ramp, and what should be done in the future to better manage ramps and the forecast error around ramps.

This event analysis has proven to be one of the most beneficial methods to understand the capabilities and techniques of wind power forecasting. The forecasters have been very open to critiquing their own methods and providing constructive feedback in how to improve forecasting. The following subsections outline the five special events captured to date along with the lessons learned from each event. The detailed analysis and forecaster comments can be found on the AESO website.[8]

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[8] http://www.aeso.ca/gridoperations/13870.html

4.2.1 06 September 2007

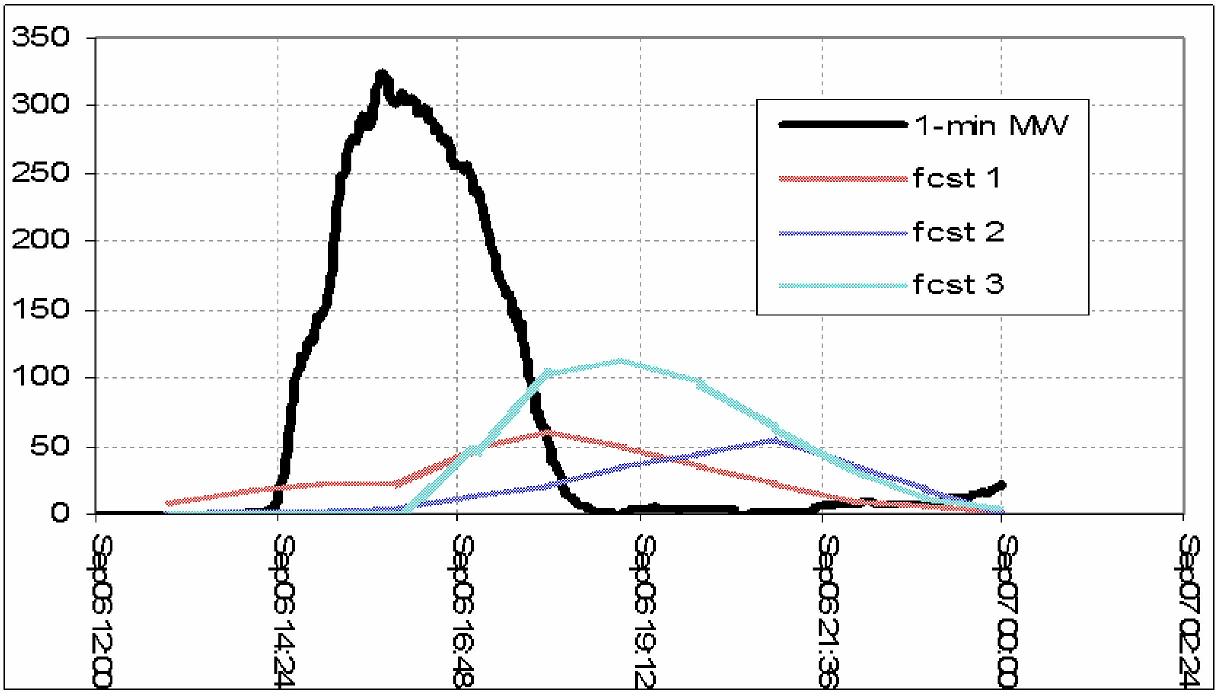

Figure 2 – Forecasts Delivered at Noon 06 Sept 2007

This event has proven to be extremely beneficial. It demonstrates many factors that need to be understood before implementing wind power forecasting into operations. The forecasters were essentially caught off guard by a northerly wind with a steep vertical movement hitting the existing facilities almost all at the same time causing a steep ramp up, followed shortly by a steep ramp down. All of which was missed in the day-ahead forecasts, and its phase and amplitude was missed in real time (T-1). The following lessons were drawn from this event:

- System operators must be prepared and have operating procedures in place for this type of forecast error. Even in the very short term, extreme forecast error is possible.
- None of the national numerical weather models (NWP) from the Canadian Meteorological Center (CMC) and the US National Center for Environmental Predictions (NCEP) had a good signature of this event in their outputs. If this is the basis for the forecasts, unless these NWP models are improved, forecast error will likely always exist.
- A higher resolution NWP model may have captured the event. However, with higher resolution, there may be more false alarms and there is a higher computational cost so there is a trade off.
- A faster update of the CMC GEM model output would have been helpful. It currently updates every 12 hours, whereas the NCEP (US) model updates every

6 hours. In addition to a faster update, a faster distribution to the public with shorter or fewer delays in the process will help.

- The forecast models are optimized to provide low MAE or RMSE values as a default. In doing this, the models sacrifice performance on extreme events however it is these extreme events that are most important to system operators. This led to the discussion that perhaps the standard metrics used to evaluate forecast performance will not work for system operator's purposes.

- The forecaster's models may have had an ensemble member or model member that saw this event signature however, given it was an outlier, it was ignored. The information of importance to the system operator would have been that there may have been a large amount of uncertainty associated with this forecast.

- Off site, wind speed measurements looking north might help predict events like this.

- Vertical shear measurements may be required to capture extreme vertical movements such as this event.

4.2.2 10-11 October 2007

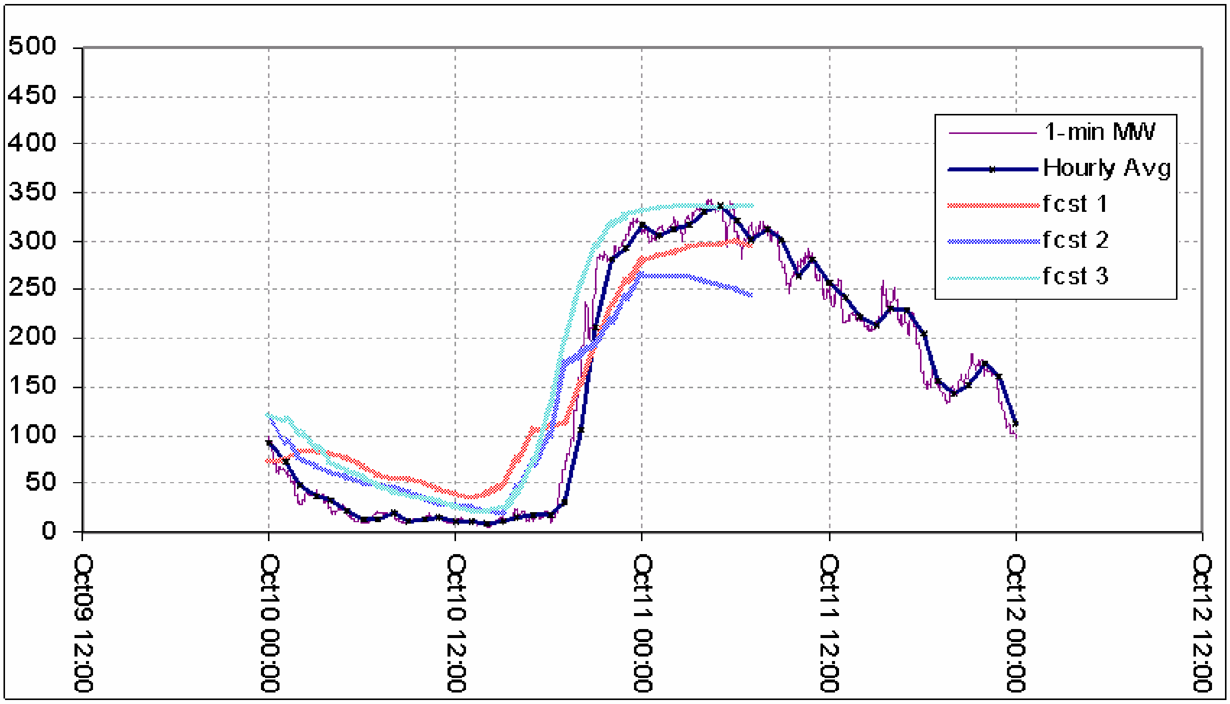

Figure 3 – Forecasts Delivered at 07am on 09 October 2007

This event was a fast ramp up on 10-11 October 07 from near zero to full output. The following lessons were drawn from this event:

- It is possible to forecast a ramp such as this up or down a day ahead.
- The difference between 6 Sept and 10-11 Oct is that the underlying weather event was larger in scale and easier to predict. This would translate into a forecast with much more certainty than the one delivered on 06 Sept.

4.2.3 26 November 2007

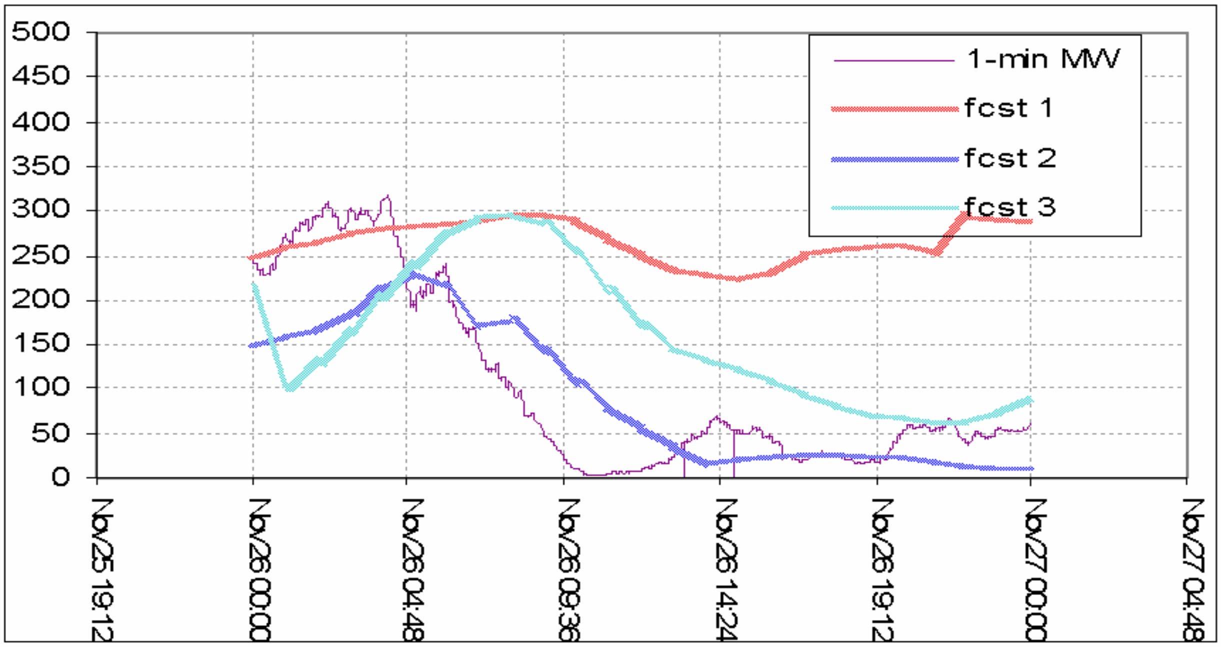

Figure 4 – Forecasts Delivered at 07am 25 November 2007

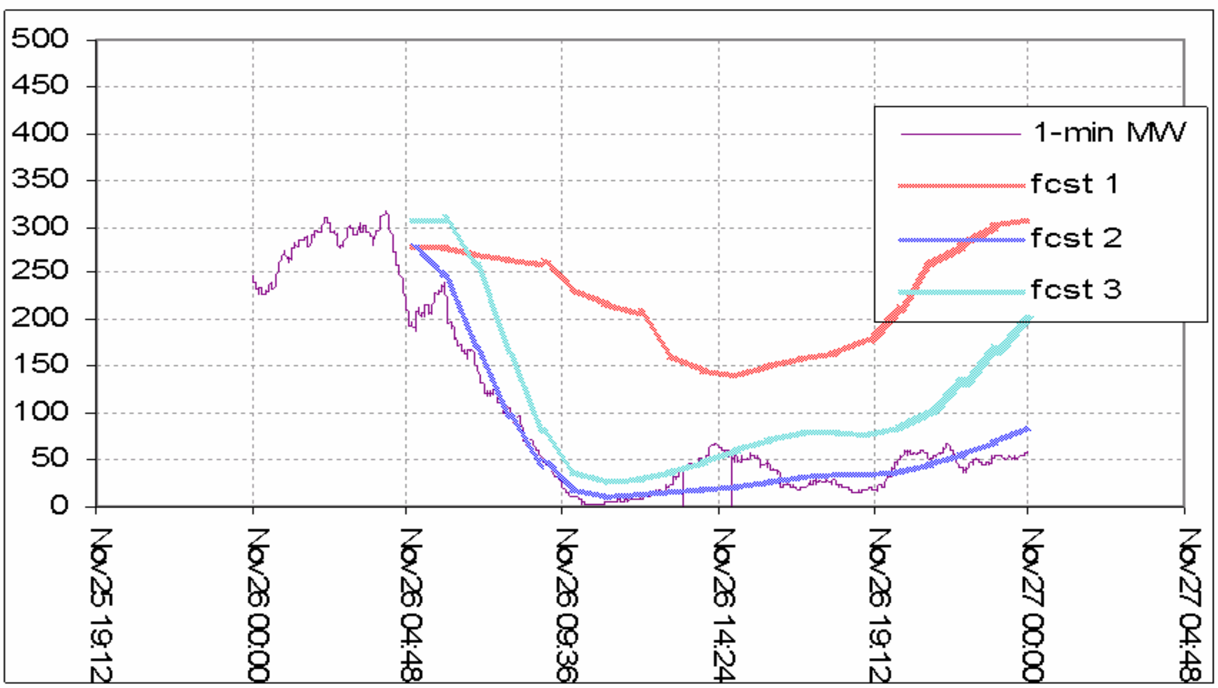

Figure 5 – Forecasts Delivered at 4am on 26 November 2007

This event was a fast ramp down on 26 November 07. This event provided some good insight into what poses to be the most challenging ramping event to system operators. System operators envision being able to handle fast ramps up with wind power management, however it is uncertain how a system operator may manage fast ramps down, especially when it was not forecasted to go down. The following lessons were drawn from this event:

- Three different models can output three completely different forecasts all depending on what they are trained to respond to in the global and national state estimates or model outputs.

- A fast ramp down of wind power can be completely missed by a wind power forecast and system operators need to be prepared. Even close to real time forecasts can miss the ramping event in amplitude and phase timing as seen in figure 5.

- However, two of the forecasts did capture the event in real time. The difference being that the one forecaster that missed the event didn't give weight to their model outputs that captured the signature. They could have predicted a high level of uncertainty or possible forecast error as a result of these outlying model outputs.

- Better use of local measurements could have made up for low resolution underlying NWP models.

- The more of these events that are seen, the better the statistical corrections made by the models will be. As time goes on, the performance of the models will improve. Until a good historical dataset is created, higher resolution models or more local area measurements may be needed.

4.2.4 2-5 December 2007

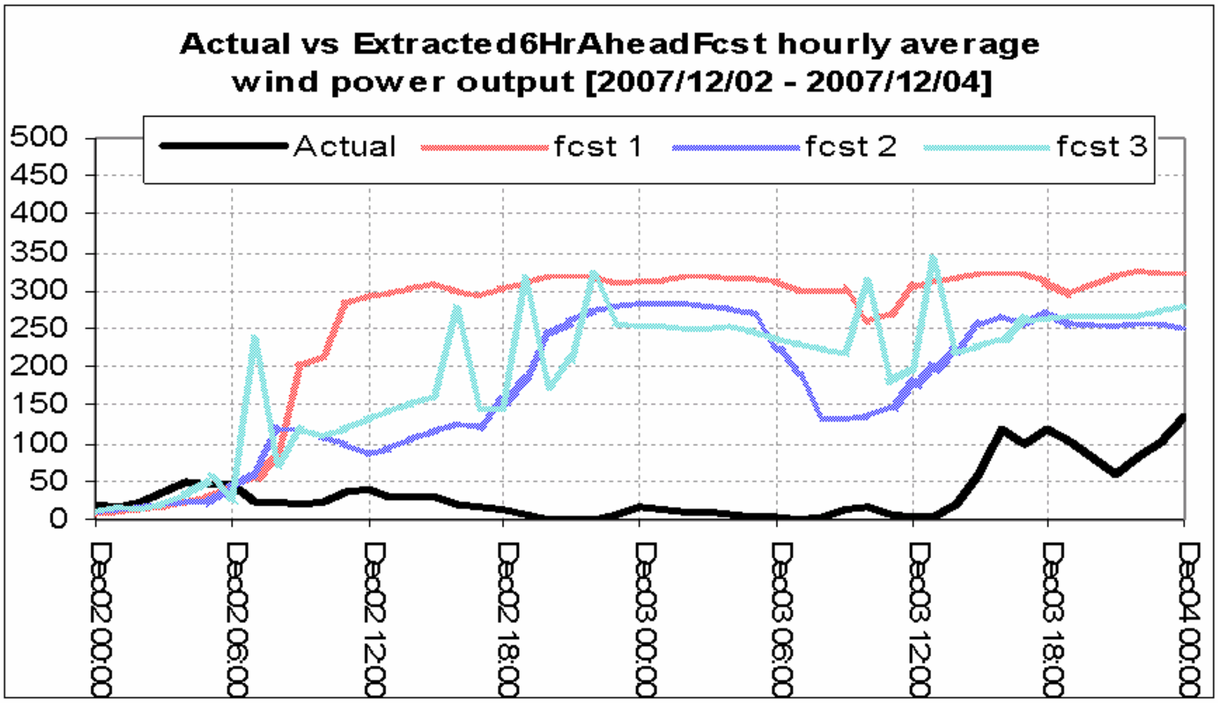

Figure 6 – Extracted T-6 Forecasts from each hourly forecast from 12am 2 Dec to 12am 4 Dec 07

This event was a forecasted ramp up of wind power that never did unfold. All three forecasters predicted a ramp up to high levels of wind power over three days. As each hour went by, the forecasts corrected to where the actual wind power ended up, but then predicted the ramp up. The analysis examined what was driving this, and how can we uncover this type of event in the future. The following lessons were drawn from this event:

- The error was generated in the NWP models that incorrectly predicted vertical mixing of high altitude fast wind speeds with surface wind speeds. Most NWP models have not been focused on surface wind speeds, and as such can generate this type of error.
- There were two facilities that tripped offline during this event period. The forecasters don’t have this information and would have continued to forecast high wind power based on the predicted wind speeds. As such, the models need to be tied into turbine or facility availability.
- In addition, when the facility tripped, the observed wind speed levels also went to zero. The met tower’s power needs to be untied from the electrical connection of the facility because the forecasters need the local measurements in order to be able to generate an accurate picture of the unfolding weather.

4.2.5 27 January 2008

This event provided an opportunity for the AESO to analyze a predicted ramping event before it unfolded. On Friday, 25 January, the AESO received an email from one of the forecasters indicating that they feel that on the afternoon of Sunday, 27 January, there was going to be some weather volatility with possible extreme ramps of wind power. Although their own submitted forecast model output did not show an extreme condition due to the fact that it is optimized for low MAE and RMSE, the underlying weather pattern has historically had a lot of uncertainty.

In summary the email indicated that a cold front is predicted to come in from the NW sometime between 2-6 MST causing a ramp down of wind power starting with the most westerly facilities. However, there will be warm air mass with strong winds on top of this cold air shortly there after setting up the conditions for vertical mixing and a possible extreme ramp up of wind power.

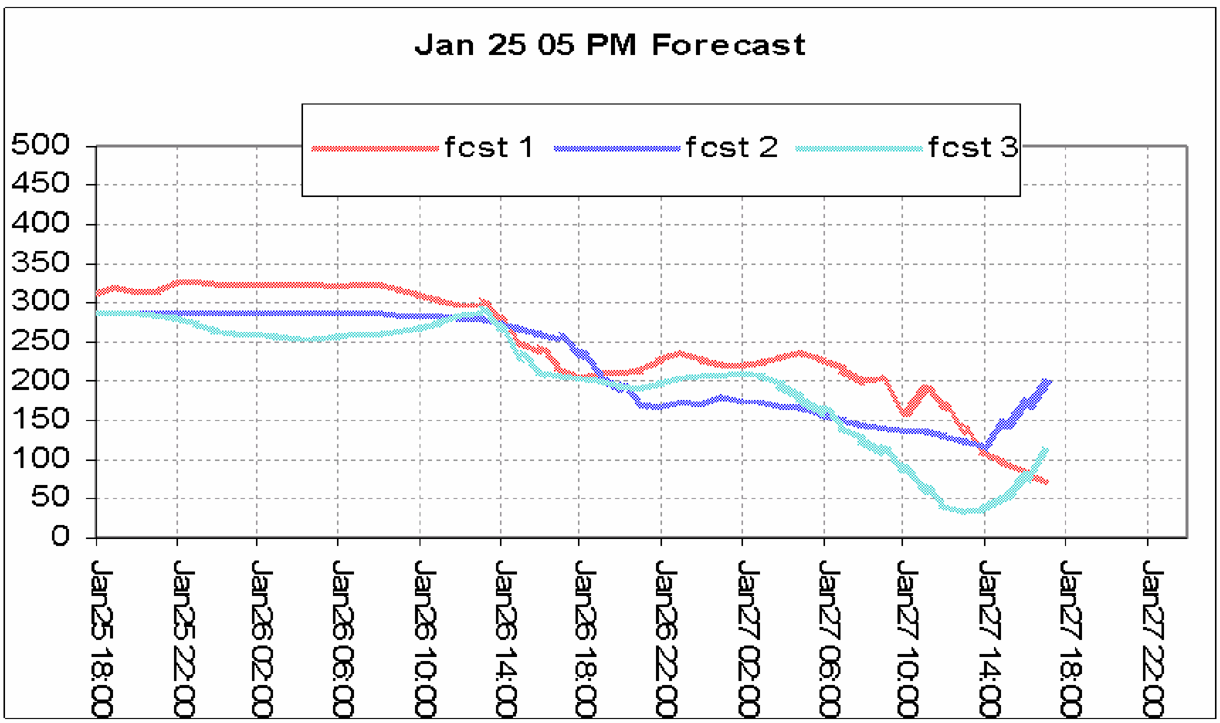

Figure 7 – Forecasts Delivered at 5pm on 25 Jan 08

Looking at some of the other forecaster's submissions showed that there was a lot of uncertainty in the Sunday's weather. WEPROG's graphical user interface displays the spread of their ensemble forecast which translates in the level of certainty associated with their best guess forecast. As the spread increases, so to does the uncertainty. As can be seen in Figure 8, WEPROG shows a growing uncertainty in their forecast delivered at 1200 on 25 January for the next 72 hours into Sunday afternoon.

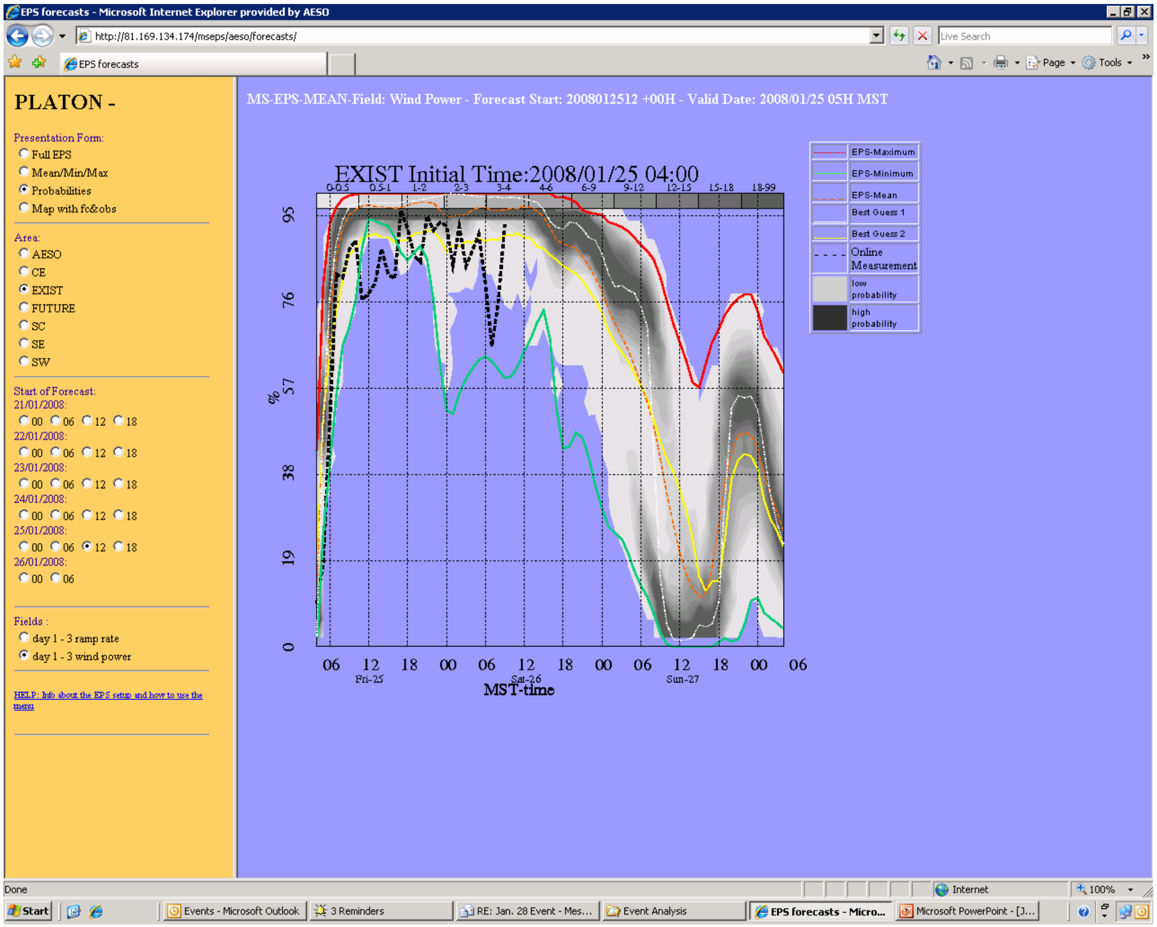

Figure 8 – Demonstration of Uncertainty Forecast

On Sunday, 27 January, the AESO system controller on shift logged that he witnessed some extreme ramps up of wind where some facilities went from zero to full in 10 minutes. Figure 9 captures the actual event and the forecasts delivered at 11am on 27 Jan 08 just prior to the ramp up. The feedback from the system controller was that any heads up that an extreme event is possible would be helpful from a system controller's perspective to avoid getting lulled into not watching the wind power screens due to its average stability.

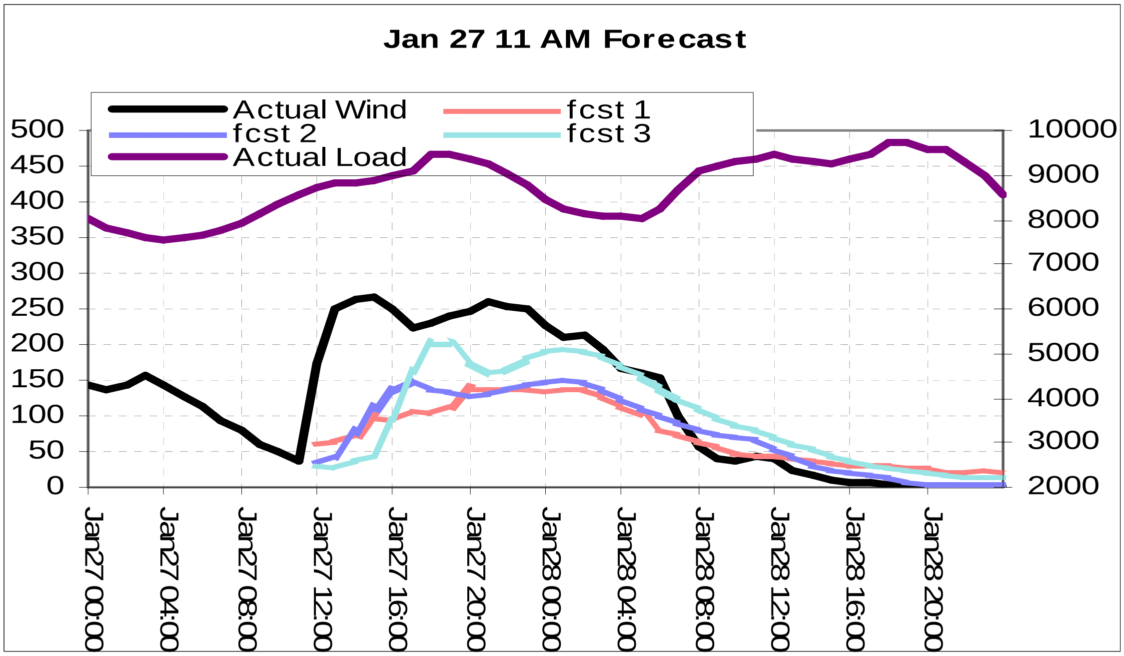

Figure 9 – Forecasts Delivered at 11am 27 Jan 08

The following lessons were drawn from this event:

- The uncertainty associated with a forecast may be as important as the forecast itself. The AESO needs to learn how to make use of the uncertainty associated with a forecast.
- Perhaps a short description of the possible wind power pattern that might unfold during a day would be of use to a system controller so at the very least they are not caught off guard.
- It seems that although the automated models themselves may not predict the wind power pattern, the forecasters seem to be able to make a manual assessment that identifies the possibility of extreme weather and as such uncertainty.

The AESO and the forecasters will continue to capture special events where lessons can be drawn so as to communicate to the industry to aid the decision determining how to best implement wind power forecasting.

4.3 The Weekly Market and Operational Wind Reports

The AESO initiated the Weekly Market and Operational Wind Reports[9] at the end of November 2007. These reports include many statistics relating to wind power from the previous week from capacity factor to curtailment statistics. The reports also

[9] http://www.aeso.ca/gridoperations/14246.html

demonstrate how wind power fits into the energy market and how it impacts the energy market. The final section aims to capture events of interest from the wind power forecasting project during the previous week. The analysis does not get into the detail of the special event analysis, however it does provide our stakeholders an opportunity to become accustom to what a wind power forecast looks like and what its capabilities are in terms of accuracy and error both phase/timing and amplitude. They also provide a valuable signal to the market that ramping resources are required to accommodate wind generation. These weekly reports will continue for the duration of the pilot project.

4.4 The Forecaster Comments

Throughout the project, the forecasters have provided very open and candid discussion providing comments and responses to any and all questions asked to them. This openness has proven to be invaluable to the project. After the end of the delivery of the second quarter (1 Dec 07), each forecaster was asked to provide a general wish list of what they would like to see in order to improve their forecasts based on their experience to date. This was meant as a small prelude to the final reports expected at the end of the project where the forecasters will summarize their lessons learned from their experience in forecasting in Alberta for a year, what they think is needed to be done in order to improve forecasting, and their recommendations for how wind power forecasting should be done in Alberta including methods and technical requirements. These reports are likely going to deliver the biggest value to the project providing the most insight into the original project objectives.

The wish lists outlined the following suggestions:

- More representative wind farm anemometer data. The anemometer needs to be strategically located and not subject to wake losses from turbines
- Accurate observed availability data of turbines and facilities
- Forecasted availability data for look ahead periods
- Sensors that can measure vertical wind shear and stability in vicinity of the wind farms
- Offsite towers that can provide information for short-term forecasts
- 6-hr forecasts cycles with longer forecast periods from Environment Canada's NWP models
- Support for Alberta Specific Wind Forecasting Research. This project will uncover the problems. A further research project will be required to develop solutions.
- More complete and timely real-time datasets from existing met towers. There needs to be fewer outages

- Increased spatial resolution of NWP models
- Pressure measurements from the BC side to estimate the pressure gradient from the Alberta side to the BC side of the Rockies
- Higher resolution objective analysis in time and space from Environment Canada (Canadian Meteorological Center)
- SYNOPTIC and Radio Sonde data in a radius of 500km to assist in developing the weather picture
- Historic and real time high frequent radar images to study lee wave movements
- Precipitation, soil and snow depth measurements on the wind facilities to improve topography models

Another important forecaster experience to highlight at this stage is that they have found that their methodology needs to adjust to the season. As the seasons change from summer to fall to winter, the wind patterns change as well with average lower wind speeds and extreme ramps in the summer moving to average higher wind speeds and less frequent extreme ramps in the winter. This impacts the overall error that the models are subject to. As the forecasters better understand the seasons, they will be able to train and adjust their models to account for the seasonal differences.

4.5 The AESO Analysis

As discussed in section 4.1, it has become apparent that there needs to be a new method developed to evaluate forecasting performance, specifically in relation to performance regarding ramping events. The special event analysis and the weekly wind reports have demonstrated that there is phase error associated with forecasting that is not well understood or quantified. This phase error does not show up in the raw statistics of MAE or RMSE. Though the dispersion component of RMSE can be broken out to represent phase error, it is not in a language that is meaningful to system operations. That language is simply time in minutes or hours.

The AESO has developed a new approach to quantitatively evaluate forecast performance of ramping events. This is exploratory based on what we have learned from the pilot project forecasts, and the AESO is currently seeking input from forecasters and stakeholders as to its validity and use. The following outlines the steps taken in understanding how well ramps are captured.

4.5.1 Step 1 of AESO Analysis

Isolate all ramping events in a measured aggregate wind power dataset by finding times where the following criteria are met:

- Any continuous + or - change in wind power greater than 20% of the installed capacity. The rational for the 20% factor is that it represents a significant ramp when the installed capacity reaches large scale.

- The rate of change is more than 20% of installed capacity per hour

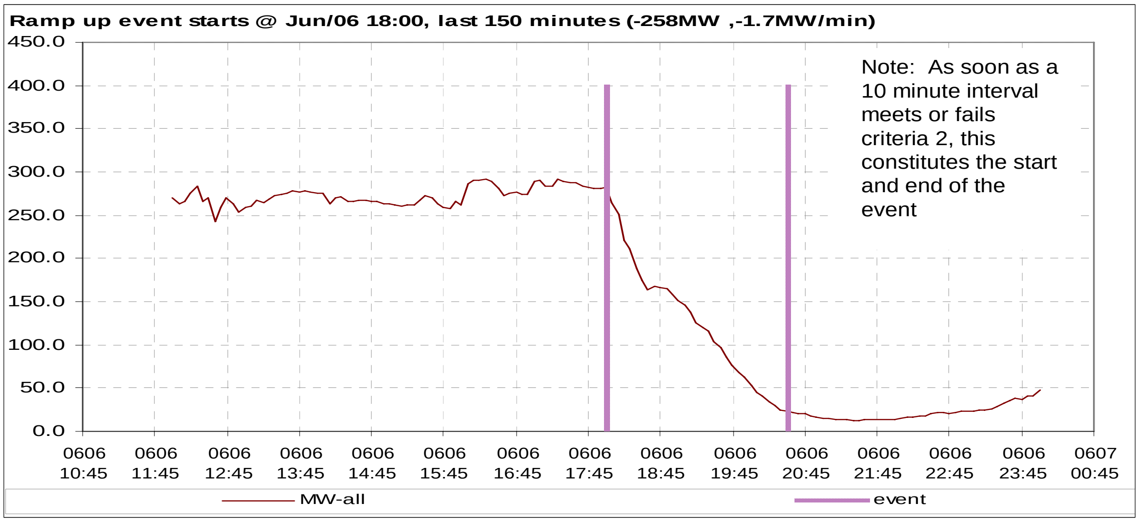

Figure 10 – Step 1 of AESO Event Analysis

4.5.2 Step 2 of AESO Analysis

Find the "best fit" for each forecast to the isolated event by scanning the forecasts from the start of the event back 6 hours and forward 6 hours to find the closest forecasted ramp in magnitude. Apply the same time frame limits as defined by the actual event to the start of the forecasted ramp. From this the magnitude error and the phase error can be quantified.

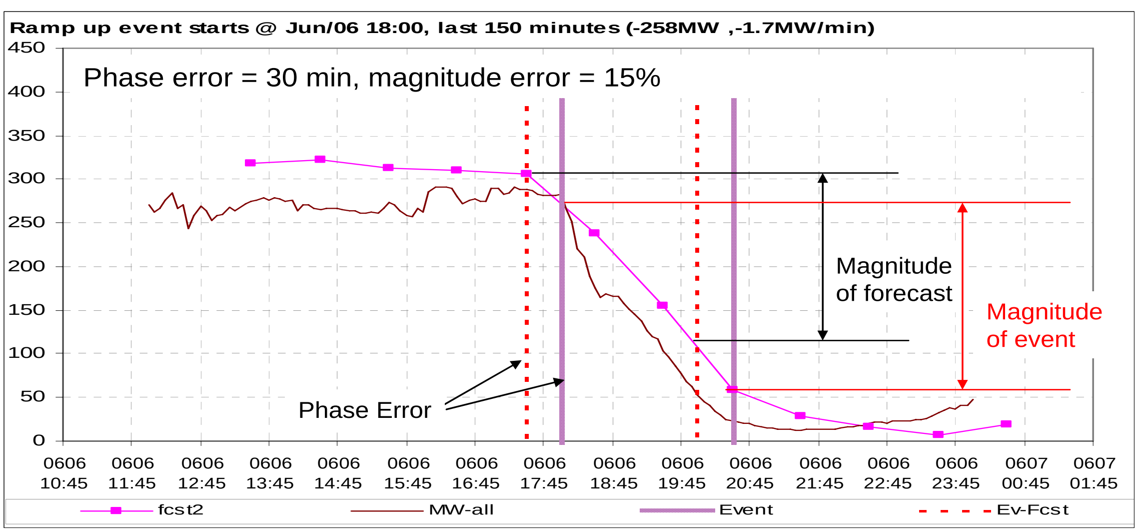

Figure 11 – Step 2 of the AESO Event Analysis

4.5.3 Graphical Results

The results can be graphed in the format as shown below against an example shaded target area. A negative magnitude error signifies an over forecast. When all the events are plotted on this graph, trends may begin to appear. It should be possible to identify the events by weather pattern or by ramping direction and color those events differently on the graph to identify error trends. This may tell you for example that Northerly winds result in negative phase error. This may also provide a means to identify a target which may translate into a performance requirement in the future. The main purpose is to allow for an understanding of the combined error of phase error and magnitude error.

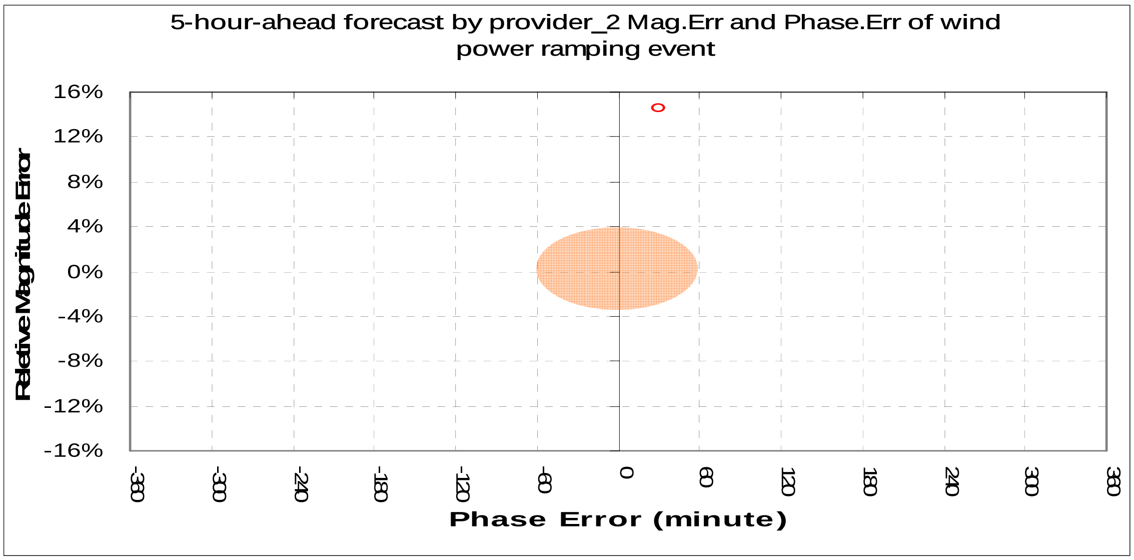

Figure 12 – Graphical Demonstration of the AESO Analysis

4.6 AESO/Environment Canada Collaboration

As a result of the special event analysis and the wish lists discussed in section 4.4, it became apparent that Environment Canada's NWP GEM model and its data infrastructure can play a key role in the success of wind power forecasting. The AESO engaged Environment Canada (EC) very aggressively to try to dig into what the strengths and weaknesses are in relation to its NWP models to ensure that they are aware of the areas to reinforce or improve. In doing this we learned about some of the EC initiatives in this research area. These include the development of a 2.5 km higher resolution GEM model where the current publicly available GEM outputs are based on 15 km resolution. The update frequency is also being explored with a goal of updating every 6 hours versus the current 12 hours. These discussions with EC has also led to uncovering many other sources of publicly available observation data in the Alberta area from weather balloon launches and aviation sound data. The usefulness of these additional data sources are being explored by the forecasters.

One of the areas explored with EC was the contribution of the NWP models to the apparent phase error in the forecasts. These discussions brought about the notion that while this phase error is apparent in weather forecasting, having an expert meteorologist assessing the automated model forecasts against the large scale weather pattern unfolding in real time should have a positive impact to phase error. Essentially a professional weather forecaster should be able to correct the phase error imbedded in the forecasts.

The AESO is interested in validating this assumption and is working with EC to set up a controlled experiment to trial this. The intent is to collaborate with EC by having them assess the aggregate forecast from the existing facilities and provide their assessment as to the possible phase error of any forecasted ramps, the possible uncertainty associated with the forecast, and to provide a general description of the possible wind power pattern for the next day based on the weather forecast generated by EC. The AESO will report on this controlled experiment at the end of the project.

5.0 Summary

The pilot project continues to be a tremendous learning experience for all involved and all those following its progress, and is on track to meet the objectives outlined in section 2.0. The design of the project has and continues to facilitate a great deal of qualitative and quantitative analysis. One leading indicator of project success will be determined by how these lessons are communicated to industry such that the appropriate forecasting method is chosen and implemented into Alberta. There are various methods being used to ensure these lessons are communicated to industry to inform on techniques and capabilities of wind power forecasting. These methods continue to be optimized in order to extract the greatest value.

At this stage of the project there is a much better understanding of the capabilities of wind power forecasting, the techniques behind wind power forecasting, and how wind power forecasting may be used in Alberta. It is prevalent that phase error exists and must be understood in order to be managed. The AESO will continue to develop its event analysis methodology described in section 4.5 to facilitate this understanding. The event experiences are also indicating that the uncertainty associated with a forecast may be as important as the forecast itself and should be considered as a part of the forecast. In addition to having a forecast and its uncertainty, having a high level of situational awareness of the unfolding weather pattern may also be of value to system operators. The AESO and the Work Group will continue to explore these ideas as the project progresses. Final reports are expected by June of 2008, and the Work Group recommendation to the AESO is expected by September of 2008.

APPENDIX I. Detailed Project Design

High Level Design

The following outlines the high level design of the project.

- Trial three different forecasting methods via three vendors with an assortment of background and jurisdictional experience
- Delivery of 48 hour ahead forecasts every hour of the day for an entire year to capture all seasons of the year and all hours of the day
- Forecasts provided for 12 separate wind power facilities geographically spread out across southern Alberta
- Of the 12, seven are existing facilities and five are future facilities. A future facility consists of a meteorological tower and a projected wind facility power curve provided by Genivar (formally Phoenix Engineering)
- Southern Alberta broken into 4 zones characterized by similar wind patterns, each zone represented by three of the 12 facilities
- Phoenix Engineering performs meteorological data collection to provide to forecasters
- ORTECH Power to conduct independent quantitative analysis

Input Datasets

The following details the data collected by Phoenix Engineering in order to enable to the forecasts:

- 10 minute historical meteorological data for model training purposes is collected by Phoenix including 1 x met tower at or near each of the twelve sites sensing temperature, pressure, wind direction, and wind speed (1 year). Height of each measurement is recorded and provided to forecasters
- 10 minute real time meteorological data collected by Phoenix includes 1 x met tower at or near each of the twelve sites sensing temperature, pressure, wind direction, and wind speed. Height of each measurement is recorded and provided to forecasters.
- Data collected via Second Wind Nomad 2 loggers and sent to Phoenix via satellite feed
- Phoenix Wind Server conducts quality control of the meteorological data
- 10 minute historical aggregate facility power SCADA for model training purposes is provided from the AESO to Phoenix (1 year)
- 10 minute real time aggregate facility power SCADA is provided from the AESO to Phoenix
- Real time and historical Meteorological data and power SCADA made available to forecasters on Phoenix servers every 10 minutes
- Where available, facility turbine availability data is provided to the forecasters (some being 10 minutes and others hourly)
- Turbines power curves provided for facilities. After Aug 2, facility power curves were provided for the future facilities

- Wind Power Facility configurations provided for existing facilities including (but not in all cases) turbine type, number of turbines, specific location of turbines, wind facility capacity, and hub height)
- Other than free publicly available data, the forecasters were not authorized to make use of any other data in their forecasts
- All met towers were calibrated by April 20, 2007. Before this day there were select sensors reporting inaccurate readings to due to wrong calibrations.
- Summary of input data as per "Forecasting Project Data Forecast" spreadsheet below. Wind power facility configuration data includes in the following order as per the table below: 1- turbine type, 2 - number of turbines, 3 - specific turbine locations, 4 - wind farm capacity, 5 - hub height, 6 - turbine power curve.

Site		Hist Met Data 2006	Hist Power Data 2006	Hist Met Data 2007	Hist Power Data 2007	Hist Op Avail Data 2006	Real Time Met Data	Real Time Power Data	Real Time Op Avail Data	WPF Config Data					
Operator	Name									1	2	3	4	5	6
CanHydro	Cowley Ridge	Yes	Yes	Yes	Yes	n/a	Yes	Yes	n/a	Y	Y	Y	Y	Y	Y
TransAlta (VQ)	Summerview	Yes	Yes	Yes	Yes	n/a	Yes	Yes	Yes	Y	Y	Y	Y	Y	Y
TransAlta (VQ)	Castle River	Yes	Yes	Yes	Yes	n/a	Yes	Yes	No	Y	Y	Y	Y	Y	Y
TransAlta (VQ)	McBride Lake	Yes	Yes	Yes	Yes	n/a	Yes	Yes	Yes	Y	Y	Y	Y	Y	Y
Suncor	Magrath	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Y	Y	Y	Y	Y	Y
Suncor	Chin Chute	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Y	Y	Y	Y	Y	Y
Enmax	Taber	Yes	n/a	Yes	n/a	n/a	Yes	n/a	n/a	Y	Y	n/a	Y	Y	Y
CanHydro	Soderglen	Yes	Yes	Yes	Yes	n/a	Yes	Yes	Yes	Y	Y	Y	Y	Y	Y
Future 1	Future 1	Yes	n/a	Yes	n/a	n/a	Yes	n/a	n/a	Y	Y	n/a	Y	Y	Y
Future 2	Future 2	Yes	n/a	Yes	n/a	n/a	Yes	n/a	n/a	Y	Y	n/a	Y	Y	Y
Future 3	Future 3	Yes	n/a	Yes	n/a	n/a	Yes	n/a	n/a	Y	Y	n/a	Y	Y	Y
Future 4	Future 4	Yes	n/a	Yes	n/a	n/a	Yes	n/a	n/a	Y	Y	n/a	Y	Y	Y

Table 1- Summary of Site Input Data

Output Datasets

The following outlines the details of the deliverables from the forecasters and Phoenix:

- No later than 15 minutes after the hour, forecasters deliver a T-1 to T-48 hour inclusive forecast including maximum, minimum and average wind speed, wind direction, temperature, and air pressure at a single location in each facility, maximum, minimum, and average wind power and ramp rate (Note: energy and meteo does not provide maximum and minimum forecasts nor air pressure forecasts)
- Temperatures are forecasted at a 2 meter height while all other met data is forecasted at the height it is measured
- Wind direction is defined as a vector mean
- Ramp rate is defined as the expected MW/hr for each hour and the positive or negative sign is required
- Minimum and maximum values as defined by each forecaster
- Power conversion at future facilities assumes the following:
    - Apply a linear interpolation of the turbine power curves provided by Phoenix from May 1 to Aug 2, and of the facility power curves provided by Phoenix from Aug 2 onwards.
    - Apply a 4% wake loss.
    - Model as 50 MW facilities, except Taber is to be modeled as an 81.4 MW facility.

- Phoenix is to use real time meteorological data and apply the same power conversion principles to generate an estimated observed power dataset for future facilities to be compared against the forecasted power at future facilities
- Output datasets include an aggregate wind power and ramp rate forecast for each zone, a total aggregate wind power and ramp rate forecast, and an aggregate wind power and ramp rate forecast for the existing facilities (including the minimum and maximum)
- Where turbine availability is not provided, forecasters are permitted to make their best guess on what the turbine availability is.

ORTECH Analysis

The following outlines what will be covered in the ORTECH Power quantitative analysis.

- ORTECH will perform a detailed analysis of the following for each forecasting model:
  - The general accuracy of the Forecasts,
  - The accuracy of the Forecasts at the different forecast horizons studied (T=1 hour to T=48 hours),
  - The accuracy of the Forecasts at different hours of the day and seasons of the year,
  - The accuracy of the Forecasted Metrological Data before running through the Power Conversion models,
  - The accuracy of the Power Conversion,
  - Potential co-variance from given data samples,
  - The accuracy of the Forecast at different wind speeds or different points of a Wind Power Facility's power curve,
  - The relative comparison between Forecasts from two or more providers, and
  - The validity of the Forecast methodologies used and their strengths and weaknesses.
  - The trend of the Forecast performance through time.
  - Forecast accuracy for individual wind farms in the study, aggregate forecast accuracy of all wind farms considered in the study which are in the same region and aggregate forecast accuracy of all wind farms considered in the study.
  - How well the Forecast predicts fast ramp up and ramp down times,
  - Comparing all the above between Alberta Wind Regions.

- The following accuracy metrics will be used/considered:
  - Root Mean Square Error (RSME)
  - Mean Absolute Error (MAE)
  - Normalized prediction error expressed per unit of capacity or energy (in RSME or MAE)
  - Improvement over persistence in the short term (in RSME or MAE)
  - Ensemble of regions (examining the smoothing effects of more wind power facilities spread out on forecast error)
  - Principle component analysis

  - Probability of Detection and False alarm ratios to analyze extreme event or non-systematic errors

- It was decided not to initially put a priority on any accuracy metric or timeframe of forecast. The intent is to learn and understand which metric or timeframe may be most useful first, and then set a priority.

- ORTECH analysis would flag periods of time where met data was not available or where there were transmission constraints imposed on the facilities (as provided by the AESO).

- To maintain confidentiality of the facilities, results will not identify the facility by name, capacity or location (other than by zone).

- To maintain confidentiality of the forecast methods, results will not identify the forecast by the name of the vendor in the reports.

Project Schedule

The following outlines the latest schedule of the project. The schedule has shifted as the project evolved, however, the end date in the terms of the contracts and grant agreements have not.

- July - Oct 2006
  - Industry Work Group Stood up, Develop Project Design, Write Terms of Reference, and RFP development
- Oct 2006
  - Issue RFP (Wind Power Forecast and Quantitative Analysis)
- Nov 2006
  - Evaluation of Submitted Proposals
- Dec 2006 - Feb 2007
  - Contract Negotiations
  - Develop Data Collection
- Feb 2007 - April 2007
  - Data Collection, model training
- May 1, 2007
  - Forecast Delivery Begins
- Quarterly Reports
  - Oct 07, Dec 07, Mar 08
- Final Reports
  - Forecaster Reports End May 08
  - ORTECH Jun 08
- Work Group Recommendations
  - Sept 08