Final Report

Wind power forecasting pilot project in Alberta, Canada

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Responsible authors:
Ulrich Focken
Matthias Lange

energy & meteo systems GmbH
Oldenburg, Germany

Marie-Curie-Straße 1
26129 Oldenburg/ Germany

Phone: +49 441 36116 470
Fax: +49 441 36116 479

mail@energymeteo.com
www.energymeteo.com

Content of the final report

1 Executive Summary

The main findings of energy & meteo systems during the wind power forecasting pilot project in Alberta are:

- Generally, the wind farm locations in Alberta are very challenging from a forecaster's perspective. This is mainly due to the fact that the wind regimes in the area at the foot of the Rocky Mountains are quite extreme as the wind conditions can change very rapidly leading to a "binary" behaviour of the wind turbines. We did not develop specific methods for this forecasting project but because of the special wind conditions in Alberta we had to make considerable efforts to tune our models to the new forecasting situation. This tuning process has not been finished yet and in our view there is still a large potential for further improvements of the forecasting performance.
- The practical experience from the pilot project showed that for us the best way to cope with the wind power forecasting challenge in Alberta is to use
    - a selection of several well-performing numerical weather predictions (NWP) as input for the power prediction model.
    - an advanced combination of the numerical weather models weighted according to the specific weather situation. In particular, to choose the best performing model for the situations which are dominated by local wind regimes, e.g. Chinook.
    - site-specific and direction dependent power curves based on historic wind farm data.
    - an individually tuned shortest-term model for the forecast horizon 0 -10 hours ahead based on power measurements.
- With a deeper understanding of the underlying meteorological situations and continued optimization of the models we were able to continuously improve our ramp event forecasting. A feasible way of forecasting ramps is to adequately exploit the capabilities of the different numerical weather models. While one model captures the global weather situation better the other one performs better for local effects. But there are still major events which are not correctly seen by the predictions.
- In terms of the forecast evaluation the ramp events were difficult to assess because there was no strict definition in the project of what ramp really means. Thus, the accuracy of ramp forecasting was mainly rated by human intuition rather than mathematical exactness. It would be desirable to have a more standardized approach for the evaluation.
- The measurement data played a very important role during the whole project as these data are the foundation for the setup, tuning and evaluation of the forecasting models. The intense work on the project and discussions among participants brought up two major issues:
    - The availability and the quality of historical SCADA data as well as online SCADA feeds are very important. Due to the challenging locations the historical measurements from the wind farms were indispensable to optimize the forecasts during the setup of the predictions. For the shortest term forecasts (0 – 10 h) the timeliness of the SCADA data delivery to the forecasters had a direct impact on the accuracy. In the beginning the data availability left some space for improvements which was gradually filled during the project.
    - The benefit of additional meteorological measurements from masts, flights etc. was discussed elaborately among the participants. We see no immediate value which justifies large investments in additional equipment as the existing data has to be exploited first. This would make more sense for longer term improvements of the wind power prediction systems in Alberta.

- We identified areas for improvement according to different forecast horizons (short term 10 to 48 hours, very short term 0 to 10 h and ramp forecast) and the time frames where the benefits of improvements will become visible (next steps 0 - 2 years and long term improvements 0 - 5 years):
    - Next steps (0 – 2 years) with a high potential for improvement with medium work and a clear perspective of being successful:
        - Short term (10 to 48 hours ahead): Involvement of two or three extra weather models (NWP), inclusion of advanced methods for high pressure weather situations (not included yet due to time constraint), more detailed training of the combination model to distinguish certain weather patterns and seasonal effects
        - Very short term (0 to 10 hours): Improved online information on wind farm availability, improved online availability of power measurements, enhancement of shortest-term prediction module for ramp events
        - Optimized Ramp forecasting: The ramps have different meteorological reasons (frontal systems, Chinook, thermal stratification, etc.) and it is important to detect the ramp events in the weather forecast. We see that some NWP models are capable of predicting the ramps in general and that the wind power forecasting system has to be further optimized to pick out the "right" ramps.
    - Long term improvements (0 – 5 years) are identified to achieve improvements on a high level, i.e. should be realized in the context of larger R&D projects:
        - Short term (10 to 48 hours): Co-operation with weather services, e.g. Environment Canada or a European weather service, to improve NWP models with regard to wind speed.
        - Very short term (0 to 10 hours): Online assessment of the prevailing weather situation over Canada based on available online measurements and very short term forecasts.
- Form our experience in Alberta we derived the following technical recommendations with descending degree of importance:
    1. Online power measurement (SCADA) with **very high** availability
    2. Online turbine availability with **very high** availability
    3. Online measurement of nacelle wind speed and wind direction (SCADA)
    4. Online maintenance schedule (as first guess of the forecast of the turbine availability)
    5. Existing meteorological measurements from the weather service within a radius of a few hundred kilometres
    6. Extra meteorological measurements from wind towers in main wind direction
- All data should be provided in 10 min resolution. For a new setup at least one year historical data should be available for items 1, 2, 3 and 4. We would recommend a centralized collection of measurement data from wind farms by the AESO while the existing meteorological measurements can be collected by the forecast provider itself.
- Following our experience from other applications, i.e. in Germany, it would be very helpful to include human assessment into the forecasting process. This means that an expert with experience in wind power forecasting provides advice regarding the forecasts delivered by the numerical system.
- The evaluation reports for this project contained a very advanced forecast evaluation. It turned out to be difficult to supply a good overview of the forecasting performance and to compare the three forecasters. In our view the evaluation procedure improved during the project but one has to keep in mind that the first evaluation report is not really representative due to difficulties in the data availability as well as the setup and tuning of the forecasting models which was still in progress.

2 Detailed Report

This document is the final report of a one year pilot delivery of wind power forecast for the Alberta Electric System Operator (AESO). energy & meteo systems has been providing one year of operational wind power forecasts and meteorological forecasts of weather variables including wind speed, wind direction and temperature for several locations in Alberta.

The report is organized as follows. Chapter 3 describes our general experience with the project and briefly describes the way we proceeded through different phases of the project. The following chapters 4 to 11 focus on the content of the project. Most of these chapters are divided into 3 categories:

- General forecasting methods and experiences
  This is the most important topic and describes the main aspects of the forecasting experience for sites in Alberta we have made during the project.

- Ramp event forecasting
  The topic of ramp event forecasting has become more and more an issue during the year of operational delivery. Therefore, we included a comment in each of the other chapters.

- Measurement data issues
  We distinguish between two important points that have been treated regarding the measurement data
  - SCADA feeds from wind farms including power measurement, turbine availability and nacelle wind speed and direction measurements

  - Additional meteorological data
    The project in Alberta was related to intense discussions on data, especially meteorological measurements from masts. Therefore, in each chapter is also a comment due to data needed, data importance etc.

We have not included a meteorological discussion about the different weather regimes in Alberta. That would have gone far beyond the scope of this report. So we concentrate on the methodologies and recommendations for the operational wind power forecasting.

3 Wind power forecasting pilot project.

The project started in February 2007. The first 3 months were used for providing and processing historical data, initialization of the forecasts, setting up the operational data flow and the definition of sub regions.

The operational forecast period was postponed by two weeks due to difficulties with several topics and started on 1st May 2007. Within the first months of operation several changes occurred related to sites to predict, definition of sub regions, changing static data for wind farms and masts (e.g. geographical coordinates, hub heights), changing formats of data and renaming of sites, data files, and servers. Due to this it took some time for each forecaster to find the right setup for his system with the optimal tuning.

It took around 4 months to receive a phase of stable operational forecasting, without larger errors in the forecast due to wrong setup. So as far as we are concerned the last 8 months of forecasting can be reasonably evaluated. The performance strongly improved over the whole time period.

The discussion about the best way of evaluation started with the beginning of the operational forecast. The first quarterly report was a very preliminary evaluation including all the problems of the setup described above. Therefore, in our view the results presented in the first evaluation report are of limited significance and cannot be generalized. The third quarterly report was not published even though it contained a clearer evaluation based on more reliable data. The learning process regarding the best strategy of how to evaluate forecasts has not been finished yet.

Generally, the forecasting pilot project was an effective strategy for the AESO and Alberta to learn about wind power forecasting. Many persons have been educated mainly on the information provided by the forecasters. It would have been even more effective, if the AESO had used the first 2 months to define their requirements on the forecasts in more detail. Also with a more clear definition what forecast is needed a fairer comparison of several forecasters would have been possible. Now the comparison is quite difficult, because the forecasts are tuned to different strategies.

4 General Overview of experience forecasting in Alberta

4.1 General forecasting

In general, we faced a very challenging weather regime in Alberta with a large number of extreme events due to local wind effects. The level of difficulty was comparable to sites in Spain or Ireland but the effects near the Rocky Mountains were completely different.
Hence, in the beginning of the project we had to understand the meteorological weather regime in order to gradually improve the forecast accuracy.

The forecasting solution energy & meteo systems originally proposed in the beginning of the project and which already achieved very good results on other occasions turned out to be successful for Alberta.

Our forecasting solution has four major ingredients:

- Selection of good NWP input for the area of the wind farms
- Combination of several numerical weather models weighted according to the weather situation
- Site-specific power curves based on historical data
- Shortest-term model (0 -10 hours) based on power measurements

We did not develop specific methods for this forecasting project but due to the special wind conditions in Alberta we had to make considerable efforts to tune our models to the new forecasting situation.

4.2 Ramp event forecasting

The wind conditions in Alberta often lead to extremely steep ramps in the power output of the wind farms. These gradients were undoubtedly the major challenge with regard to forecasting as the behaviour of the wind energy production at several locations was "binary" at certain times, i.e. periods of low level production were followed by full load periods and fell back to nearly zero output within a few hours.

With a deeper understanding and continued optimization of the models the accuracy of our ramp event forecasting improved a lot during the project but there are still major events which are not correctly seen by the predictions. For the purpose of ramp event forecasting our multi-model approach turned out to be very helpful as the two weather models we used showed their largest differences in these events. So we focussed on selecting the model that has the best chance to capture the specific ramp event correctly in a specific weather situation.

In terms of the forecast evaluation ramps are difficult to assess because there was no strict definition of what ramp really means. Thus, the accuracy of ramp forecasting was mainly rated by human intuition rather than mathematical exactness. Though getting direct comments on the ramps from the control center is a very valuable feedback it is desirable to have a more standardized approach for the evaluation. Our experience shows that a coherent definition of ramps is very difficult. Nevertheless it is necessary if the performance of a forecaster is evaluated against his ability to forecast ramps.

4.3 Measurement Data issues

The measurement data played an important role during the whole project as these data are the foundation for the setup, tuning and evaluation of the forecasting models. The intense work on the project and discussions among forecasters, the AESO and Phoenix brought up two major issues:

- Availability and quality of historical data as well as online measurement data (SCADA feeds)
- Question of additional meteorological measurements from met masts, flights etc.

The first item is very important in our opinion. Due to the challenging locations in Alberta the historic measurements from the wind farms were indispensable to optimize the forecasts during the setup of the predictions.

Concerning the online feeds the real time availability was crucial. The degree of availability of online data steadily increased during the project. In particular, in the beginning of the project interruptions of the data delivery occurred and extended over several hours for specific wind farms. This issue was discussed among the forecasters and they suggested to evaluate only those points of times where the measured data was early enough available. But in practice it turned out to be very difficult to determine when the data had been ready for download. So the performance of the short timeframes (1 – 6 hours ahead) is governed by forecasting errors as well as missing data.

The second issue of setting up more meteorological measurements consumed a disproportionate part of the project time compared to the benefit that can be achieved by using these data. Unfortunately, the discussion about extra meteorological data sometimes interfered with the fruitful discussions about the forecasting itself. In our opinion additional meteorological information can be useful to improve the forecast accuracy and to detect critical events like ramps earlier than now. But the effort to build a sufficiently large array of met masts around the wind farm locations is very high such that the ratio between costs and benefits is quite low. In our view it makes more sense to exploit the existing data resources further and more intense.

5 Lessons learned and training

5.1 General Forecasting

Related to the very extreme weather regime, we concentrated in the first months of the project mainly on understanding the meteorological weather regime. On basis of this knowledge we focused on the strengths and weaknesses of the different numerical weather predictions (NWP) in our set up. In our understanding this was the key for a good forecast for all prediction horizons.

Our general findings were similar to findings we made in other locations. In the following we describe the specific outcome for Alberta:

- The accuracy of the NWP is crucial for the accuracy of the wind power forecast

  We started with three NWP which we initially selected for Alberta and found after a short period that one NWP has a very bad performance for all weather situations and prediction horizons, so we skipped it to focus on the remaining two.

- The combination of forecasts based on different weather models allows for an optimal weighting of the NWP according to their capabilities in different weather situations.

  Our multi-model approach for Alberta is based on the two weather models which show different forecasting capabilities in different weather situations. The combination tool classifies the weather situation and provides optimal weighting factors for each specific forecasting hour. One NWP was clearly better in the general performance and in specific situations e.g. very fast moving weather patterns. The forecast on basis of the second NWP input had significant advantages in predicting ramps and other local effects (see Figure 1).

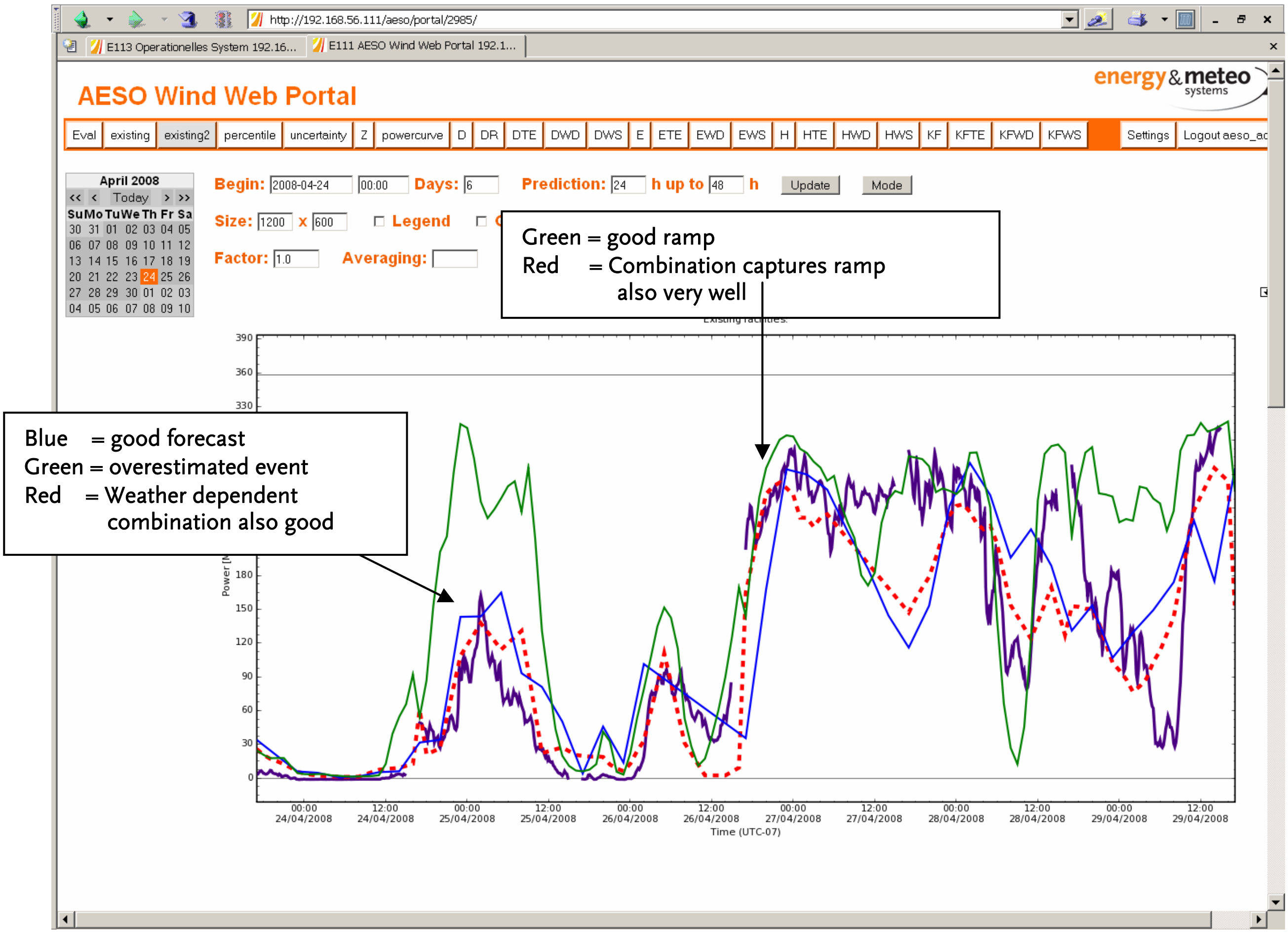


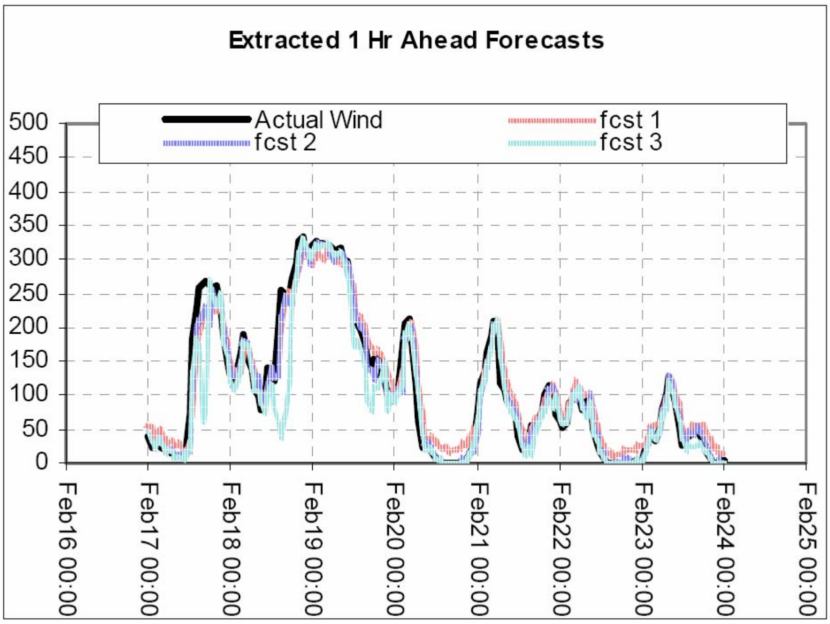
Figure 1: Ramp forecasting capabilities of the two NWP models. The graph shows the day ahead forecasts (24 to 48 h) for April 24th to April 29th 2008 with measured power of the existing facilities (dark blue line), the forecast of two independent forecasts based on two NWP (green and light blue lines) and the delivered combined Previento forecast (red dotted line). The combined forecast takes advantage of the strengths of the individual forecasts. (see weekly report April 20th to 26th).

- Site specific power curves

  The power output of some wind farms in Alberta is strongly direction dependent. So the power output changes very fast with changing direction.
  For Alberta we had to adjust our direction dependent power curve model to capture the power output with very small changes in wind direction. This was done on basis of historical NWP data and measured power output.

- Shortest term forecasts

  In the first 6 month we did not concentrate on the very short term prediction, due to the fact that the importance of this forecast was not clearly defined and knowing that we had a basic strategy for the setup to get a very good performance. So for the first 6 months our performance up to 6 hours prediction horizon was not much better than for higher prediction horizons. After a rough understanding of the weather regime in Alberta, we have integrated our shortest term model and the performance was, as expected, quite good without using any meteorological measurement for the operational set up (only used for historical training).(Figure 2).



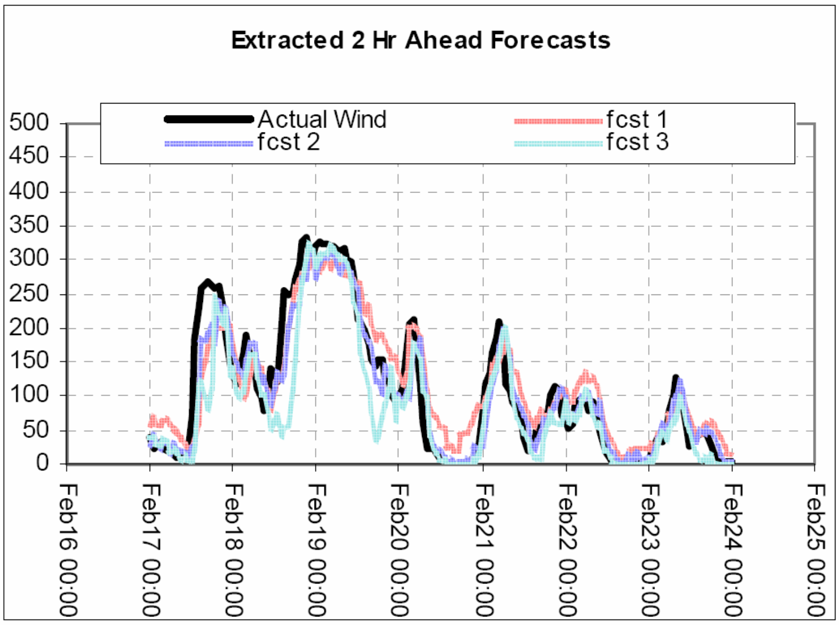


Figure 2: Extracted 1 hour (top) and 2 hour (bottom) ahead forecast compared for all forecasters. We cannot see the advantage of using meteorological measurements in this stage of the project as we used only online wind power measurement and turbine availability (see weekly report Feb 17th to 24th 2008).

5.2 Ramp events

The ramps in the power output of the wind farms were the greatest challenge. We found that a feasible way of forecasting ramps is to adequately exploit the information provided by several weather models. The two NWP we used mainly differ during ramp events. This is due to the fact that the models are different in their physical parameterization, their spatial resolution and their initial conditions. While one model captures the global weather situation due to the large weather systems better the other one has advantages in local effects like the falling winds from the Rocky Mountains.

In our opinion it is crucial to understand the meteorological conditions that lead to ramps and optimize the weighting of the NWP models accordingly. In Figure 3 several ramp events are shown where the forecasts based on the two NWP perform differently. In particular, there are ramps which are captured equally well by both models, ramps which are better predicted by the local model and ramps which are not very well seen by both of them. During the project we learned to distinguish different forecasting situations and give more weight to the "right" model. But, of course, this learning process is not finished.

Additionally, we would like to point out that the power forecasting model can either be tuned for a low rmse, i.e. low deviations on average, or the power model can be optimized for ramps, i.e. keep steep gradients. Figure 5 compares the forecasts with the two strategies. These two strategies are alternatives which cannot be merged into one. Hence, the user has to decide what type of forecast is better suited for his purposes or use both forecasts in parallel.

For the AESO case we started with an rmse optimized prediction because one of the main ideas of the project was to compare different predictions in terms of the standard error measures (like in the quarterly reports prepared by ORTECH). We think the project shows that for the case of Alberta a ramp optimized forecast would also be a good approach

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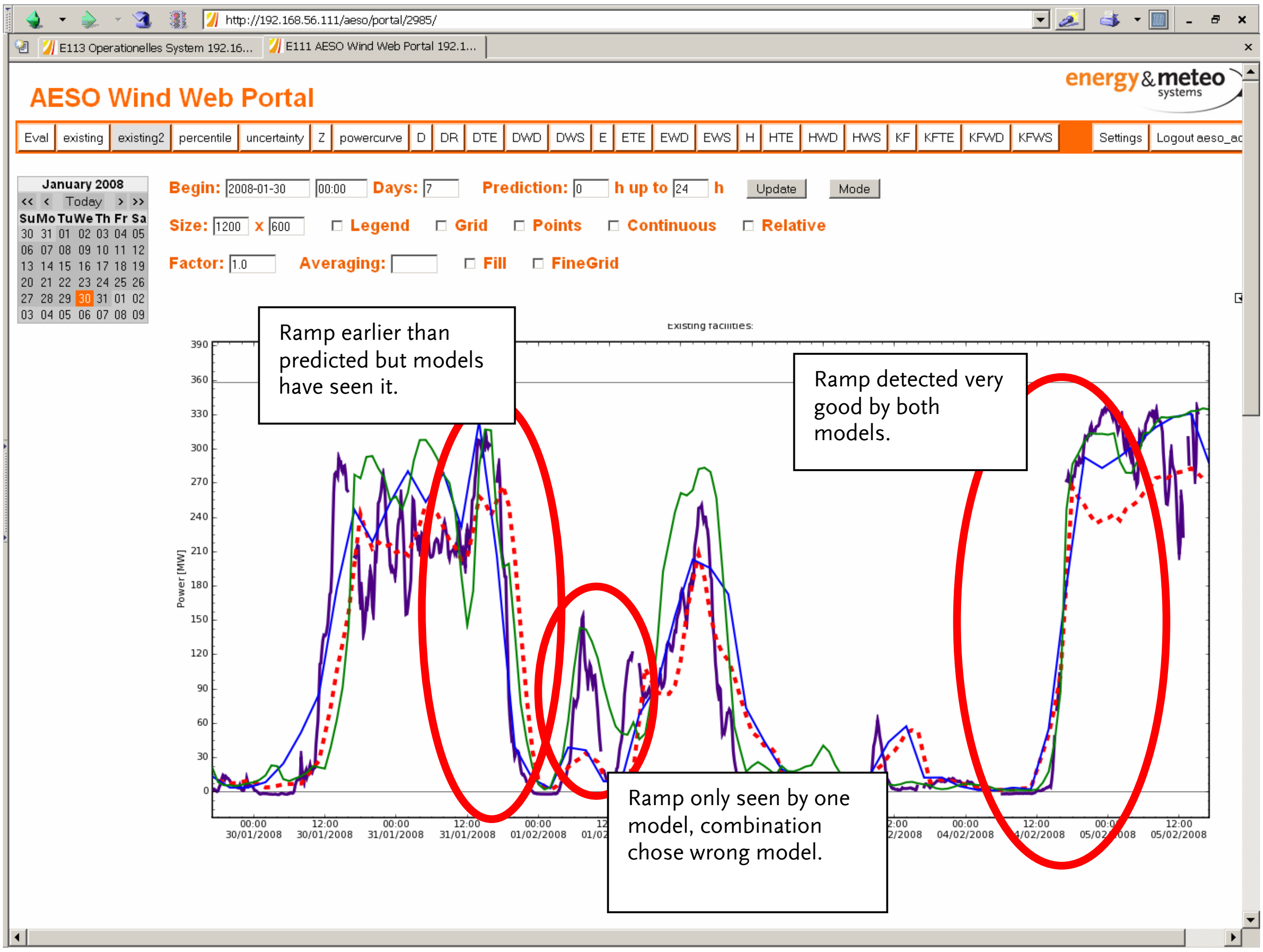


Figure 3: Ramp events are not equally well predicted by one of the weather models because they are caused by different meteorological effects. The graph shows the intraday forecasts (0 to 24 h) for January 30th to February 5th 2008. Examples of ramp forecasts with different forecasting models (green and light blue) and their weighted combination (red dotted). Even for the aggregated output of the existing facilities the ramps are very steep (dark blue line). A key to forecast the ramps adequately lies in choosing the weather model that is capable of capturing this effect and tuning the forecasting model to ramps instead of rmse.

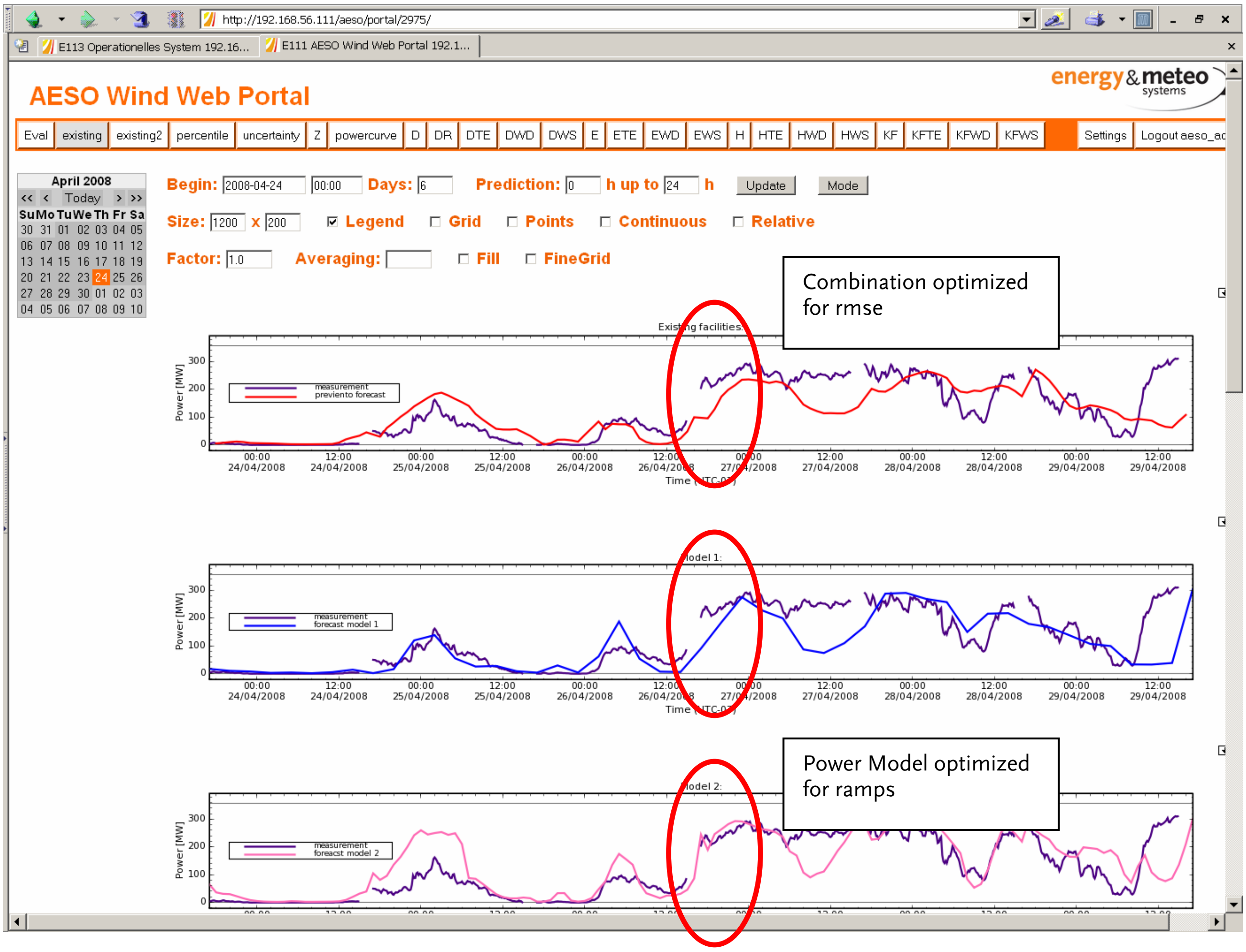


Figure 4: Tuning possibilities of the power model. The graph shows the intraday forecasts (0 to 24 h) for April 24th to April 29th 2008. Examples for different tuning of the forecasting system. It can be optimized either for the root mean square error (rmse) to achieve low deviations on average (middle) or it can be tuned to better capture ramp events (bottom).

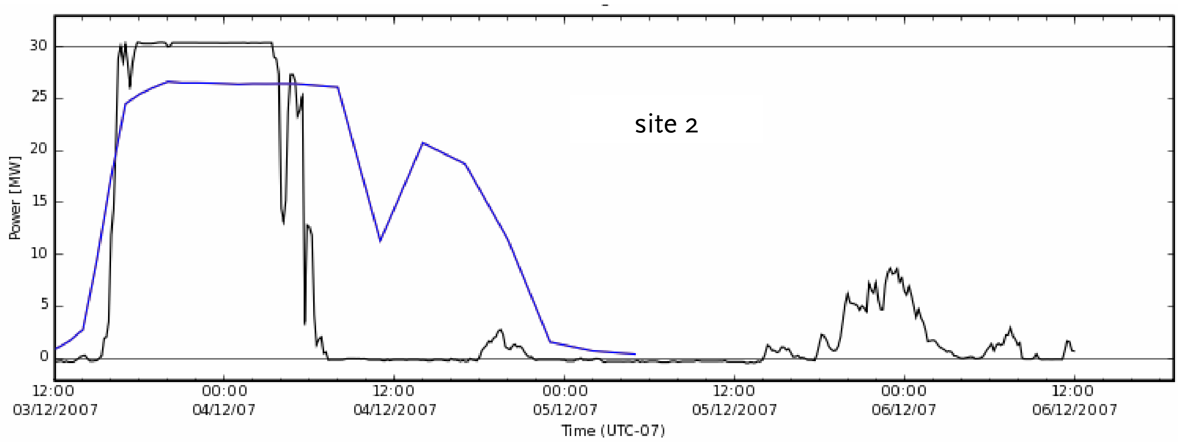
5.3 Measurement data issues

As stated before the issue of measurement data is of major importance to achieve good forecasting results in Alberta. In our experience the measurement data provided by the wind farms via SCADA has to be used as effective as possible prior to the erection of additional meteorological towers.

In general, it is very important to define which type of data is needed for a forecast. Then the requirement for data can be defined. In our opinion it is better to start with few variables organized in complete data sets having a good availability and then define step by step what extra data are needed.

We found that the minimum time period to obtain reasonable results for Alberta is at least one year of historic data, in particular power output of the wind farms but also measurements of wind speed and wind direction from the nacelle anemometer of individual turbines. If the data comprised less than one year or had large gaps the data turned out to be not representative for all seasons. The performance increased with more high-quality historic data being available.

Regarding the online data feeds which had to be provided at least hourly during the operational phase it became apparent that availability mattered most. When the online data were delayed, the shortest term forecast for the next six hours were not as good as possible (see Figure 5). As the accuracy of the forecasts was directly linked with the real-time availability and the quality of the SCADA feeds from the wind farms the non-availability had to be considered in the evaluation of the shortest time frames (1 to 6 hours) to get well-defined results.



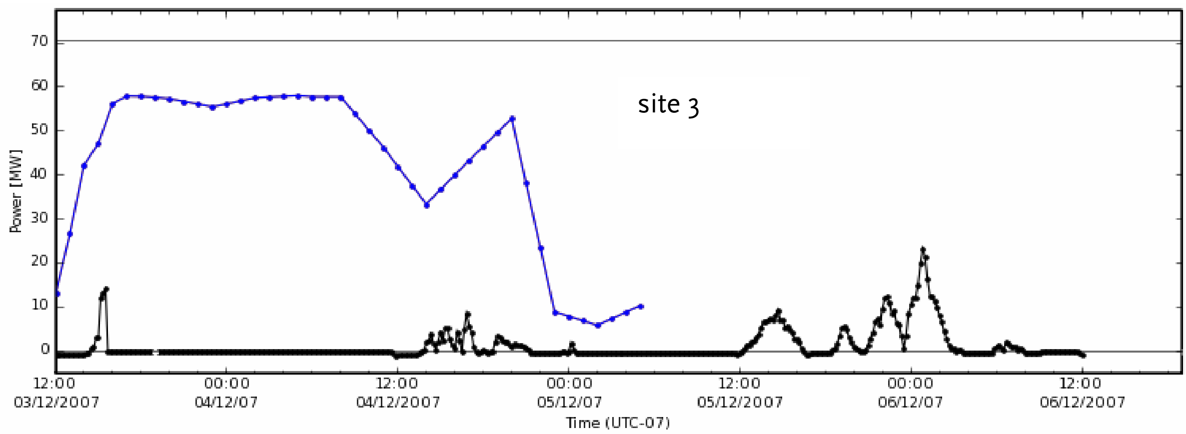


Figure 5: Measurement (black) and forecast (blue) for Dec 3rd to 6th 2007 for two very closely located wind farms. It can be seen clearly that site 3 (bottom) was not available at the beginning of the ramp for nearly one day. This resulted in an extremely wrong forecast (see event analysis Dec 2nd to 6th 2007).

Our experiences with the wind farms in Alberta so far suggest that there is still a large potential in the measurement data that is provided by the wind farms. We expect that the forecasts can be further optimized by exploiting the information contained in measurements of power, wind speed and direction from the wind farms. Therefore, we do not see that extra meteorological measurement data from met mast are needed for good forecasts now (see further improvements in section 6)

6 Areas for Improvement

The areas for improvement will be classified according to different forecast horizons (short term 10 to 48 h, very short term 0 to 10 h and ramp forecast) and time frames (next steps 0 - 2 years and long term improvement 0 - 5 years).

We distinguish very clearly between topics which sound sexy but are not the best next step and those which might sound boring but lead to improvements in the short run.

One example for something sexy but very costly: We are involved in the very big European research project "SafeWind" (including 6 TSO from 6 European countries). Our part within the project is to collect as many information on the current status of the weather as possible: weather stations from the weather services (mainly wind speed and pressure), wind power measurements, nacelle wind speed and direction measurements, radiosonde measurements to analyse the weather. These data will be compared to the forecasted weather situation. From this difference the very short term forecast (0 - 10 hours) could be determined. We will do this throughout Europe and North America. This is a very innovative project, but requires a large budget and needs a lot of development and time. In the case of Alberta we would not suggest such an approach now as there are easier things to do first.

It is important to mention that due to the number of forecasts and data, energy & meteo system has not yet finished the tuning of the models which are up and running. The highest potential for improvements is to have more evaluation time for weather classification and a detailed look into the several weather regimes. Also energy & meteo systems has not yet implemented all methods developed. Hence, there is a huge potential left, e.g. a prediction method for high pressure situations (where high ramps occur). These both would be the first steps with highest potential for further improvement.

Next steps (0 – 2 years)

These options are considered to have a high potential for improvement with medium work and a clear perspective of being successful:

- Short term (10 to 48 hours ahead)
    - Involvement of two or three extra weather models (NWP)
      In another application we found that 4 – 5 weather models are an optimal number for the weather dependent combination. In particular, we would consider the new local model of Environment Canada.
    - Include advanced methods for high pressure weather situations (not included yet due to time constraint)
      The thermal stratification of the atmosphere has a strong influence on the vertical wind profile. So far we used our stratification model that was developed for less extreme locations. We would modify this for the case of Alberta.
    - More detailed training of combination model

As said before the analysis of the measurement data that is already available to us suggests further potential to distinguish certain weather patterns. But for this purpose longer time series records are needed. In particular, we would concentrate on

- the seasonal dependence of weather patterns
- the extreme events that causes ramps
- the enhancement of our automatic weather classification

- Very short term (0 to 10 hours)
  - Improved online information on wind farm availability
    If there are outages of data due to maintenance, repair due to failures of the machines or the SCADA system, the missing periods have to be clearly marked in order to avoid bad training. For scheduled maintenance the data should be available in advance to consider this in the operational forecasts.

  - Improved online availability of power measurements
    This aspect is very important though not in the responsibility of energy & meteo systems. We suggest evaluating if the chosen solution of data transfer is the best option.

  - Enhancement of shortest-term prediction module
    From our end we see some potential for improvements in the optimization of our shortest term prediction module. Though it has been tuned during the project we would integrate ramps in more detail than it is now.

- Ramp forecasting

  The improvements mentioned above naturally include the ramp events as well but they deserve an extra consideration here. Our finding is that the ramps, i.e. steep gradients in the power prediction, have several different meteorological reasons (frontal systems, Chinook, thermal stratification, etc.).
  Before the improvement of the ramp forecast itself it is important to detect the ramp events in the weather forecast, i.e. to correctly capture the meteorological situation leading to a ramp event. This helps a lot to understand the mechanism behind the ramps and to classify the ramp events in different meteorological categories.

  A further analysis of these extreme events in terms of weather maps, re-analysis data as well as historic forecasts and measurement data will lead to an improved ramp forecasting. We see that our NWP models are capable of predicting the ramps in general. Unfortunately, not all of them at the same time. But there is a good chance to extract the "right" ramps which have the greatest probability to occur.

  For this purpose it will be very helpful that after the pilot phase a definition of ramp events will be developed (e.g. on basis of the approach of Darren McCrank)

  In addition, there is also the option to tune the power model better towards ramp forecasting. As can be seen in Figure 6 the ramp event tuned forecast captures ramps better than the rmse tuned forecast that is optimized for a low average deviation.

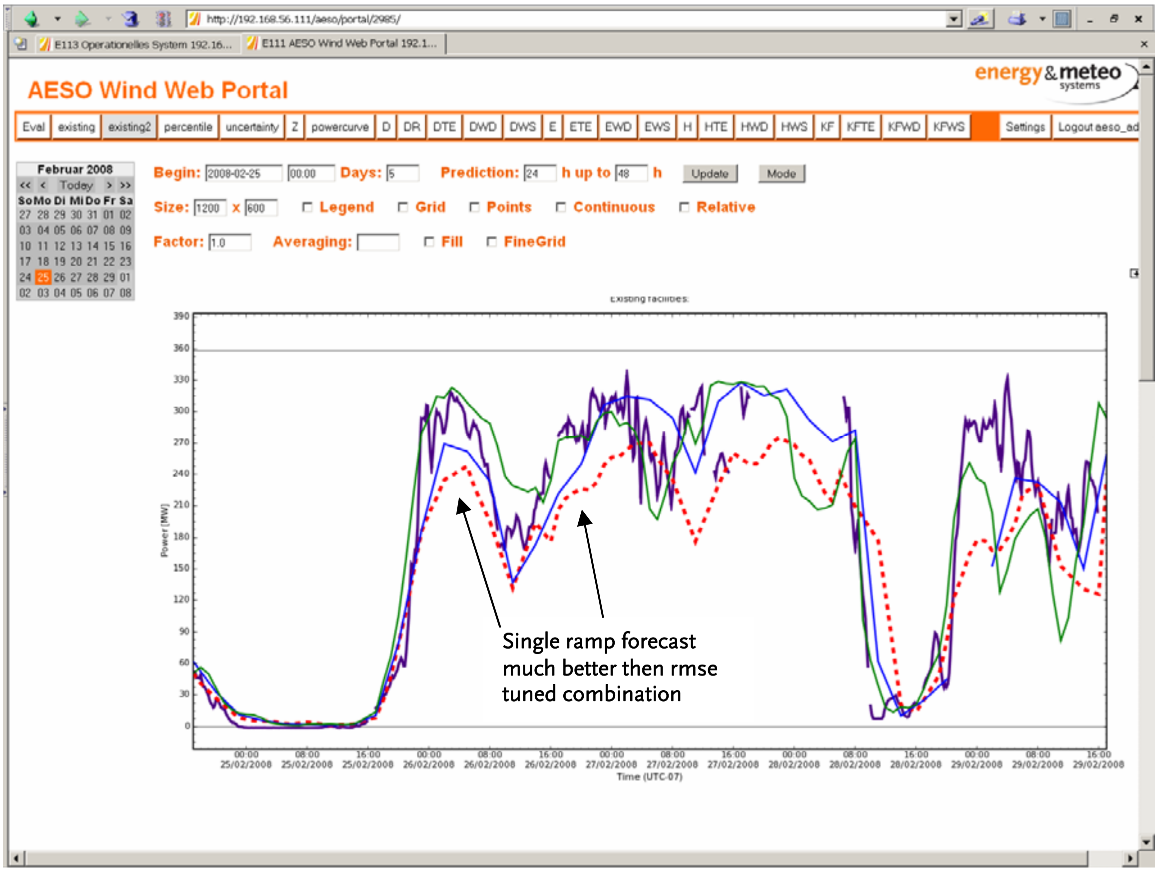


Figure 6: This graph shows the measured power for the existing facilities (indigo), the two single forecast based on different NWP input (green and blue) and the combined, delivered combined forecast (red doted). Forecasts are displayed for day ahead (24 to 48 h) for each day of Feb 25th to 29th 2008. The single forecasts are much better ramp event forecasts than the delivered one due to the RMSE tuning of the combination. There is significant potential for a ramp event forecast using a ramp event triggered tuning. (see weekly report Feb 24th - Mar 1st 2008).

Long term improvement (0 – 5 years)

The options in this section are identified for the last percentage of improvement, so in case we have already improved a lot. These options are time consuming and require a significant budget while the perspectives for major improvements are not as clear as in the previous section.

- Short term (10 to 48 hours)
  - Co-operation with weather services to improve tuning of the NWP model to wind speed instead of temperature (also provide measurements for evaluation). Possible weather services could be Environment Canada or a European weather service.
- Very short term (0 to 10 hours)
  - Online assessment of the prevailing weather situation over Canada on basis of all available online measurements and very short term forecasts (see description of "SafeWind" project above)
    - other wind farm data: power, wind speed, wind direction

- data from synoptic weather stations
- wind measurements (towers)

This can only be realized in the context of larger R&D projects where the two distinct communities of weather services and providers of wind power predictions work closely together. In Europe this approach is currently in progress.

7 Centralized versus Decentralized

We strongly recommend a centralized forecasting system

- It is very difficult to install a method which guarantees that the best possible market schedule equals the best possible forecast and the wind farm operator tend to optimize against the market (see experience Spain below).
- The wind farm operator always tries to save money. Therefore, he might not invest into a good forecast. Strategies to force the wind farm operator to invest money are always complicated and difficult to implement.

Experience in Spain

- The market participants have to provide a forecast of the anticipated power output of their wind farms to the TSO Red Electrica Espana. This forecast is similar to the schedule provided to the spot market. The wind farm operator has the opportunity to adjust the schedule several times until 2 hours before real time. Due to changing prices for day ahead and intraday there was a difference in the best possible forecast and the best schedule for the day ahead spot market. Therefore the TSO never got the best possible forecast.

8 Technical Requirements Recommendations

As mentioned already there were many discussions about data needs. Therefore, we will make two general comments before we give our recommendations for data needed for good forecasts in detail.

Resource assessment versus forecasting

There is a very large difference between wind power resource assessment and wind power forecasting. The error of the assessment is mainly defined by the error of the meteorological measurements. In contrast to that the error of the wind power forecast is mainly defined by the error in the meteorological forecast. Therefore, meteorological measurements are not so essential for a good forecast.

Avoid data overkill

As we have seen within the last year it is difficult to define what a good power forecast for Alberta is. The very general approach of the project, e.g. to gain a broad knowledge on all possible aspects of wind speed and wind power forecasting including a discussion with several meteorological forecasters causes much work on several topics, so that often time was missing to concentrate on the main topic: a good wind power forecast.
In the end it was difficult and time consuming to have an adequate evaluation of the wind power forecasts and there was no time left for the evaluation of temperature forecasts, wind direction forecasts, even wind speed forecasts.
Similar with extra meteorological data: energy & meteo systems have not used any of the extra provided meteorological data. The integration, e.g. measurements from airplane flights for some days in a year would have meant lots of work without proven success. We focused on the tuning of our model, the weather classification, the situation dependent combination and even now there is much more potential left for improvements than the integration of extra meteorological data would help. This could be done after 2 years of operation after we realized the major steps forward a good forecast based on simpler approaches.

Data recommendations

Based on our experience in Alberta and elsewhere in the world we recommend the following list of technical requirements and needed data. The list is a ranking, so the first point is most important for the forecast accuracy and the last one has not such a great influence.

1. Online power measurement with **very high** availability
   This is very important for tuning of site specific power curves and for very short term forecast.

2. Online turbine availability with **very high** availability
   Important to calculate the historical "real" generation if all turbines would be available to avoid wrong training of site-specific power curve. It is important to correct the online measurement for very short term forecast.

3. Online measurement of nacelle wind speed, wind direction
   If turbine power and availability are delivered by the wind farm it is no additional effort to deliver also the nacelle wind speed and direction. Not much work which helps a lot.

4. Online maintenance schedule (as first guess of the forecast of the turbine availability)

5. Existing meteorological measurements from the weather service within a radius of a few hundred kilometres.

6. Extra meteorological measurements from wind towers in main wind direction

All data should be raw data provided in 10 min resolution. For a new setup at least one year historical data should be available for 1, 2, 3 and 4. The existing meteorological measurements can be collected by the forecast provider itself.

The data 1, 2, 3, 4 should be collected centralized by AESO or a consultant.
This ensures:

- Straightforward communication to wind farm operators
- Not to be dependent on one forecast provider, simple set up for several forecast provider possible
- Evaluation possible at AESO

9 Uncertainty forecast

The uncertainty of the forecasts for sites in Alberta is very high compared to other locations in the world due to the binary behaviour of the wind farms. Therefore, the 70% uncertainty intervals we delivered were quite large (see Figure 7). This level of confidence means that the probability to find the real measured value within the given uncertainty interval is 70%. The experience in Alberta shows this level of confidence is a reasonable range which can really help to get an impression of the possible uncertainty of the forecast (see Figure 7). In case the number of wind farms will be increased in the future the uncertainty of the aggregated output will decrease due to smoothing effects. Then the uncertainty range, i.e. the confidence level of the uncertainty interval could be increased slowly to 80 % or even 90 %.

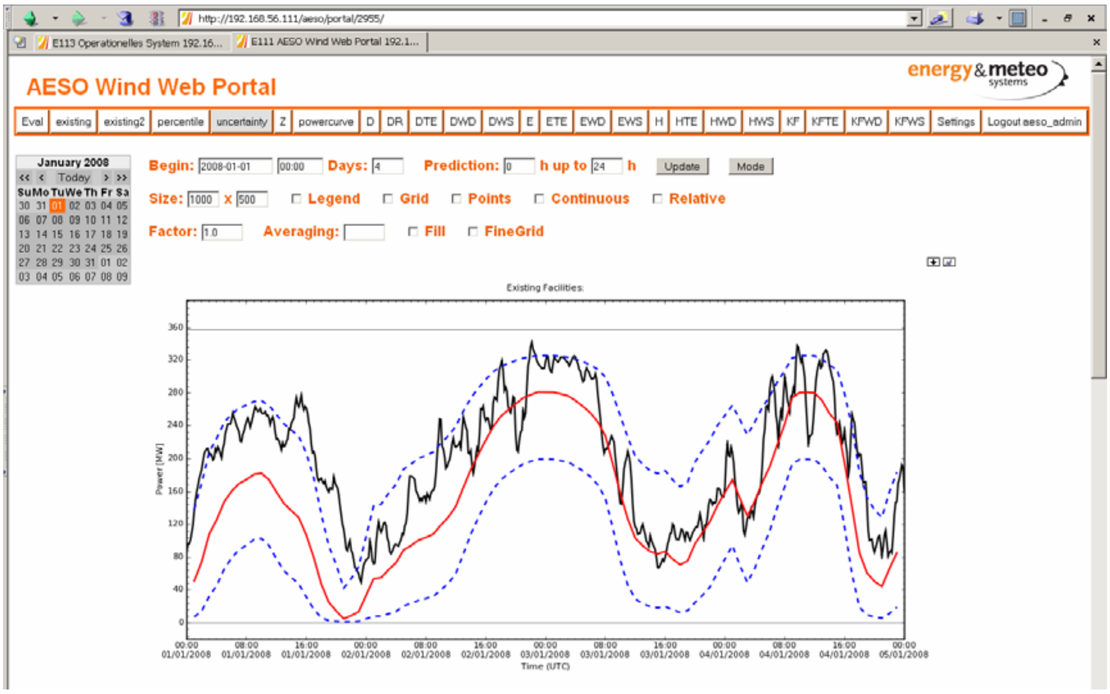


Figure 7: The graph contains the 0 to 24 hours forecast for each day from January 1st to January 4th 2008. The measurement of the existing facilities (black), the Previento forecast (red) and the uncertainty intervals (blue dashed line) (see also weekly report for this period).

Our definition of uncertainty guarantees a certain level of confidence. The dispatcher can rely on the assumption that 70 % of all forecasts are within the uncertainty interval. Together with the display of several forecasts this would be helpful to the operator.

10 Human Assessment

Human assessment means that a human expert checks the forecasting results of the wind power prediction model. He knows the weather situation, e.g. by weather charts or satellite pictures, and uses his experience to evaluate how plausible the forecasting results are. Then he communicates his assessment to the control room.

Our experience in Germany shows a very high impact of a human assessment on the forecast. The human assessment is mostly not able to improve the forecast itself, but provides a very good assessment of the uncertainty of the wind power forecast.

The human assessment should be based on different NWP input, such that the specific strength of an NWP can be detected over time in connection with weather forecast information like weather charts etc.

The human assessment should be carried out by the wind power forecaster. The improved understanding due to a by day by day view on the forecasts would help a lot to also improve the automatic wind power forecast, e.g. the improved automatic weather classification.

11 Evaluation

Ortech did a very advanced forecast evaluation. It was seen in this year that it is very difficult for other people than the forecasters to get value out of an advanced evaluation including probabilities etc.

It is more valuable to look in the beginning at examples, like single events and the "simple" error measures BIAS, MAE and RMSE. After getting a feeling for a good forecast it is possible to define error measures more in detail using the framework of the application of the wind power forecasting. At this stage it may be also possible to define a cost function for prediction errors to evaluate the real cost of prediction errors.