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WindSENSE Project Summary: FY2009-2011

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1. Introduction

Renewable resources, such as wind and solar, are providing an increasingly larger percentage of our energy needs. To successfully integrate these intermittent resources into the power grid while maintaining its reliability, we need to better understand the characteristics and predictability of the variability associated with these power generation resources. WindSENSE, a three year project at Lawrence Livermore National Laboratory, considered the problem of scheduling wind energy on the grid from the viewpoint of the control room operator. Our interviews with operators at Bonneville Power Administration (BPA), Southern California Edison (SCE), and California Independent System Operator (CaISO), indicated several challenges to integrating wind power generation into the grid. As the percentage of installed wind power has increased, the variable nature of the generation has become a problem. For example, in the Bonneville Power Administration (BPA) balancing area, the installed wind capacity has increased from 700 MW in 2006-2007 to over 1300 MW in 2008 and more than 2600 MW in 2009 (see Figure 1, left panel). To determine the amount of energy to schedule for the hours ahead, operators typically use 0-6 hour ahead forecasts, along with the actual generation in the previous hours and days. These forecasts are obtained from numerical weather prediction (NWP) simulations or based on recent trends in wind speed in the vicinity of the wind farms. However, as the wind speed can be difficult to predict, especially in a region with complex terrain, the forecasts can be inaccurate. Complicating matters are ramp events, where the generation suddenly increases or decreases by a large amount in a short time (Figure 1, right panel). These events are challenging to predict, and given their short duration, make it difficult to keep the load and the generation balanced.

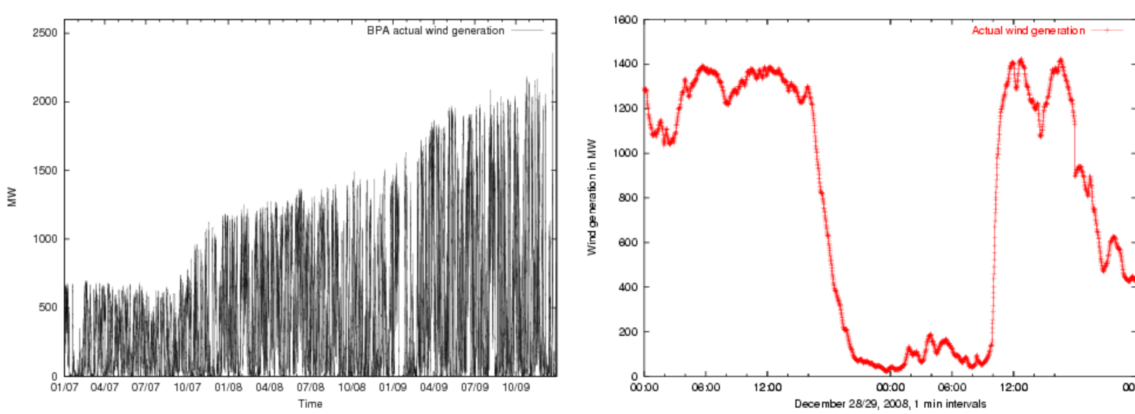

Figure 1: Left: the actual wind power generation at BPA 2007-2009. Right: Ramp events in the total wind generation at BPA during December 28/29, 2008. The up ramp on December 29 just before noon was an increase of 800MW over 30 minutes, while the down ramp at around 6pm was a drop of 233MW in 1 minute.

Our conversations with BPA, SCE, and CaISO indicated that control room operators would like 1) more accurate wind power generation forecasts for use in scheduling and 2) additional information that can be exploited when the forecasts do not match the actual generation. To achieve this, WindSENSE had two areas of focus: 1) analysis of historical data for better insights, and 2) observation targeting for improved forecasts. The goal was to provide control room operators with an awareness of wind conditions and energy forecasts so they can make well-informed scheduling decisions, especially in the case of extreme events such as ramps.

1. Analysis of historical data

In this part of the project, we analyzed data from the wind farms in the Tehachapi Pass in southern California and the mid-Columbia Basin region near the Washington-Oregon border. The power from Tehachapi Pass feeds into the grid through Southern California Edison (SCE), while the wind farms in the mid-Columbia Basin are part of the Bonneville Power Administration (BPA) balancing area. We analyzed data from 2007-2008 for SCE and 2007-2009 for BPA. There were three aspects to our analysis:

1. **Using simple statistical analysis of historical data to understand wind ramp events** [13,15]: In this work, we considered several different definitions of ramp events and addressed questions such as: how frequently do the ramp events occur, what is the relative severity of positive and negative ramps, and are the ramp events likely to occur during certain times of the day? Our analysis indicated that there is little difference among the different definitions of ramp events. Instead, factors such as the magnitude of the change and the time interval over which the change occurred are more important; these are utility specific and depend on how well the utility can tolerate such events. We also found that statistics on ramp events provided greater insights into their severity levels, their time of occurrence during the day, and their occurrence by month. While the results of such an analysis will be different for different regions, and depend on the locations of the wind farms and the amount of wind generation, it can none-the-less provide grid operators additional information they can use in balancing the load.

2. **Associating weather condition with wind ramp events** [7]: In this work, we further investigated ramp events to determine if they could be associated with weather conditions in the region of the wind farms. Our analysis of SCE and BPA data indicated that certain weather conditions at each site were associated with days with ramp events. Also, we could use these weather conditions to build a model, such as a decision tree, that could predict days likely to have ramp events. By identifying the important weather variables, we reduced the number of data streams the control room operators need to monitor, while the use of a predictive model gives them additional information they can exploit to better prepare for days likely to have ramp events.

3. **Understanding diurnal patterns in wind power generation [**3,4,6**]**: In this work, we investigated diurnal patterns we had observed during a visit to SCE, where the generation for several days had a similar pattern, with a high near midnight, a fall to near zero by mid-day and then a rise again by late afternoon. A closer analysis of longer-term SCE and BPA data indicated that there were several such patterns in the data. We investigated this further to determine if the number of such patterns was limited and to see if we could use weather conditions to predict the pattern for a day. Our analysis indicated that there were indeed diurnal patterns in the data, though given the small size of the data, some of the patterns occurred infrequently. For SCE, we also found a seasonal dependence of the two frequently occurring patterns. Despite the small size of the data, we found that we could use weather conditions to predict the patterns, especially the frequently occurring ones. However, additional analysis with larger data sets is required, not only to increase the examples of minority patterns, but also to mitigate any effects of yearly variations in the weather conditions.

2. Observation targeting for improved forecasts

In this part of the project, done in collaboration with AWS Truepower, we identified the locations and types of observations that can most improve short-term and extreme-event forecasts. Wind generation forecasts based on computer simulations are driven by observations assimilated into the time progression of the simulation. It has been found that observations of certain variables at certain locations have more value than others in reducing the forecast error for the variable of interest, at the location of interest, for the appropriate look-ahead period. To investigate this further, our work focused on the following:

1. **Application of the Ensemble Sensitivity Analysis (ESA) approach for the Tehachapi summer regime** [11, 12, 14]: In this work, we used ESA to identify measurement locations and variables that have the greatest positive impact on the accuracy of short-term (0 to 6 hour ahead) wind speed forecasts for the Tehachapi Pass area in the summer months. This was the first application of the ESA method to the problem of observation targeting for short-term wind power forecasting. We used an ensemble of perturbed NWP simulations for a sample time period and calculated the sensitivity of the target variable (the 80m wind speed at Tehachapi) to selected variables at prior times at all points in the domain. We then identified the variables/locations with the greatest sensitivity using the Multiple Observation Optimization Algorithm (MOOA), formulated specifically to determine the relative predictive value of different combinations of variables/locations. The differences in results between ramp cases and all cases were investigated by analyzing all time periods and a subset of ramp periods Our analysis showed that the forecast sensitivity was characterized by well-defined localized patterns for a number of variables such as the 80m wind speed and the 25m-1km temperature difference prior to the forecast time.

2. **Application of ESA for Columbia Basin summer and Tehachapi winter months** [9, 10]: We extended our earlier ESA work to the winter regime in Tehachapi and the warm season in the mid-Columbia Basin. We found that the differences in the warm season patterns between the two sites were consistent with the physical processes that drive the wind patterns in the two areas. The primarily warm season, diurnal cycles that dominate the weather in Tehachapi Pass result in well-defined sensitivity patterns, while the mid-Columbia Basin region is affected by larger scale flow regimes, resulting in less defined and weaker sensitivity patterns. The most consistently sensitive variables for the mid-Columbia Basin were the 80m wind speed, the 10m-80m wind shear, and the 2m-80m vertical temperature gradient. In contrast, the application of ESA to Tehachapi winter months indicated noisy and widely scattered sensitivity values due to an extremely low spread in the ensemble. We concluded that both the seasonal weather regimes and the exact configuration of the ESA-MOOA method have a dramatic influence on the ESA results and the resulting guidance for the design of sensor networks intended to improve forecast performance. We also identified several factors that could have led to the low spread for further investigation.

3. **Data denial and observation system simulation experiments for the mid-Columbia Basin** [1, 2, 5]: In this work, we attempted to validate our ESA-MOOA approach using i) data denial experiments, where we compare two forecasts, one generated with key observation data and the other without the data; and ii) observation system simulation experiment (OSSE) which uses simulation data to generate both the new and existing observations and then evaluates the effect of including the new observations. For the data denial experiments, we studied the effect of

including all met tower data, only data at highly sensitive locations, and only data at low sensitivity locations. The warm season results indicated that assimilating met tower observations significantly improved the initial state of the atmosphere at the target locations, but imbalances were introduced causing an increase in error during the second and third hours of the forecast. The cool season results were less conclusive, and hindered by the unavailability of met tower data for the target locations. We also found that the configuration of the data assimilation system has a large effect on the amount of NWP forecast benefit that can be obtained from additional observations. The OSSEs were performed for a 9-day period for both warm and cool seasons. The warm season results suggested that assimilating a single observation at the target location improved the initial conditions, but the forecast only improved for the first look-ahead hour. The addition of a modest number of sodars at locations suggested by the ESA reduced the MAE of the 80m wind speed by 10-20% through the first 4 to 5 hours of the forecasts. Further, sodar data, with wind information at multiple levels, had a greater positive effect than met tower data at a single level. The cool season results indicated no significant improvement for the first three forecast hours. They also indicated that the same observation targeting strategy that was effective during the warm season was not effective for the cool season. This underscores the fact that there are significant seasonal variations in the sensitivity of forecasts to prior observational data and the notion that a single sensor deployment strategy will not yield optimal forecast benefit throughout the annual weather cycle. Further research is needed to evaluate the results of the data denial experiments and OSSEs carefully and understand issues such as the effect of the configuration of the data assimilation system.

3. Outreach activities

A key aspect of the WindSENSE project was the active interaction with the utilities and the dissemination of information through meetings and presentations at conferences:

- Visits to utilities: SCE (July 2009, to understand the control room operation for wind integration), BPA ramp event meetings (October 2009, December 2009, and February 2010 for presentations)
- Project update meetings at LLNL with SCE, BPA, and CaISO: August 2009, October 2010, and September 2011 (phone meeting).
- Presentations at conferences: IEEE PES Transmission and Distribution 2010 and 2012 (submitted); AMS Annual Meeting 2010, 2011, and 2012 (submitted); AWEA Wind Power 2010; and IEEE PES Power Systems Conference and Exposition 2011.

All project publications are available at ckamath.org/publications_by_project/windsense

4. Acknowledgements

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5. Publications

1. J. Zack, E. J. Natenberg, G. V. Knowe, K. Waight, J. Manobianco, D. Hanley, C. Kamath, Observing System Simulation Experiments (OSSEs) for the mid-Columbia Basin," LLNL Technical Report LLNL-Tr-499162, September 2011.

2. J. Zack, E. J. Natenberg, G. V. Knowe, J. Manobianco, K. Waight, D. Hanley, C. Kamath, "Use of data denial experiments to evaluate ESA forecast sensitivity patterns," LLNL technical Report, LLNL-TR-499166, September 2011.

3. M. Ndoye and C. Kamath, "Understanding diurnal patterns in wind power generation data," IEEE PES Transmission and Distribution Conference, May 2012, submitted.

4. M. Ndoye and C. Kamath, "Pattern analysis in wind power time – early results," poster, Conference on Intelligent Data Understanding, Mountain View, October 2011.

5. J. Manobianco, E. J. Natenberg, K. Waight, G. Van Knowe, J. Zack, D. Hanley, C. Kamath, "Limited-area model-based data impact studies to improve short-range wind power forecasting," AMS Annual Meeting, January 2012, submitted.

6. M. Ndoye and C. Kamath, "Pattern identification in wind power generation time series," LLNL Post-doc poster symposium, June 2011.

7. C. Kamath, "Associating Weather Conditions with Ramp Events in Wind Power Generation," 2011 IEEE PES Power Systems Conference & Exposition, Phoenix, Arizona, March 20 - 23, 2011.

8. E. J. Natenberg, S. Young, G. Van Knowe, J. Zack, J. Manobianco, C. Kamath, "Observational Targeting Using Ensemble Sensitivity Analysis to Improve Short-Term Wind Power Forecasting in the Mid-Columbia Basin," Second Conference on Weather, Climate, and the New Energy Economy, AMS Annual Meeting, Seattle, January 23-27, 2011 LLNL-ABS-448126

9. J. Zack, E. J. Natenberg, S. Young, G. V. Knowe, K. Waight, J. Manobianco, and C. Kamath, "Application of ensemble sensitivity analysis to observation targeting for short term wind speed forecasting in the Tehachapi region winter season," LLNL Technical Report LLNL-TR-460956, October 2010.

10. J. Zack, E. J. Natenberg, S. Young, G. V. Knowe, K. Waight,J. Manobianco, and C. Kamath, "Application of ensemble sensitivity analysis to observation targeting for short term wind speed forecasting in the Washington-Oregon region,"LLNL Technical Report LLNL-TR-458086, October 2010.

11. E. J. Natenberg, J. Zack,S. Young, J. Manobianco, and C. Kamath, " A new approach using targeted observations to improve short term wind power forecasts, " AWEA WindPower 2010 Conference and Exhibition, Dallas, TX, May 2010.

12. J. Zack, E. J. Natenberg, S. Young, J. Manobianco, and C. Kamath, ""Application of ensemble sensitivity analysis to observational targeting for short term wind speed forecasting,"LLNL Technical Report LLNL-TR-424442, February, 2010.

13. C. Kamath, "Using simple statistical analysis of historical data to understand wind ramp events," LLNL Technical report LLNL-TR-423242, February 2010

14. E. J. Natenberg, J. Zack, S. Young, R. Torn, J. Manobianco, and C. Kamath, ""Application of ensemble sensitivity analysis to observational targeting for wind power forecasting," 14th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS), AMS Annual Meeting, Atlanta, January, 2010.

15. C. Kamath, "Understanding wind ramp events through analysis of historical data," IEEE PES Transmission and Distribution Conference, New Orleans, April 2010.