Development and Deployment of an Advanced Wind Forecasting Technique

Project Overview

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Project Collaborator
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Industry Partners
Horizon Wind Energy, LLC
Midwest Independent System Operator

Sponsor
U.S. Department of Energy
Wind and Hydropower Technologies Program

1 OVERVIEW AND PARTICIPANTS

The overall objective of this two-part project is to improve wind power forecasting methodologies and their use in power system operations. Part 1 concentrates on surveying existing wind power forecasting methodologies and tools and identifying strengths and limitations of different approaches. We also propose to develop a new and improved wind forecasting methodology based on the survey findings. Part 2 addresses how operators of wind power plants and power systems can incorporate advanced wind forecasting technologies into their operations, in the time span from several days ahead to real-time operations. Under this part, we propose to develop improved methodologies and algorithms to incorporate the output of advanced wind energy forecasts into decision support models for wind power plant and power system operation.

We have assembled a team of experts in wind forecasting, power systems modeling, wind farm development, and power system operations. Team members include Argonne National Laboratory, INstituto de Engenharia de Sistemas é Computadores do Porto (INESC Porto), Horizon Wind Energy LLC, and Midwest Independent System Operator.

Argonne National Laboratory is a recognized leader in the development and applications of power market simulation models around the world. Argonne's software tools are used extensively by power industry participants, including regulators, system operators, transmission companies, and power generators. In supporting its clients in the United States and abroad, Argonne draws on over three decades of experience in systems analysis, electricity market and power systems modeling, investment planning, integration of renewables, and development of decision support tools.

The Power Systems Unit of INESC Porto has a portfolio of activities and is internationally acknowledged as a leader in research and technology transfer and consultancy. The unit operates in areas such as regulation and electricity markets, integration of dispersed independent producers, technical and economic management of distribution systems, and regional energy planning. INESC Porto's experience with wind modeling and wind power integration dates back to 1992. In Portugal, INESC Porto has a strong relationship with the major companies in the power sector, namely with EDP and REN (Portuguese TSO).

2 TECHNICAL DESCRIPTION OF PROJECT

2.1 BACKGROUND AND PROJECT OVERVIEW

Short-term forecasting is critical for managing the variability of wind power. Improved forecasting of wind power helps to keep down the system costs of managing the variable-output generation characteristics. Higher forecasting accuracy contributes to minimizing the probability of an unexpected gap between scheduled and actual wind generation. Present-day accuracy levels of forecasting tools for regionally aggregated wind farms are on the order of 10% for 1-day ahead (error on power output) and 5% for 1-4 hours ahead. Accurate methods for short-term wind power forecasting are widely available, as there are commercial tools and services in this area, covering a wide range of applications and customized implementations. However, substantial research efforts continue to focus on improving the accuracy and the robustness of predictions and increasing their time horizon.

In the first part, we will survey existing wind power forecasting methodologies and tools and identify strengths and limitations of different approaches. We will develop a synthesis of various aspects that will prove useful from an end-user point of view for the selection and application of short-term wind power forecasting tools. We will also identify critical areas for improvement in existing methodologies. As part of our work, we will develop a consistent methodology to assess the performance of wind power forecasting models. In the longer term, our objective is to use the results from the assessment of current forecasting tools to develop an improved model for wind forecasting in the United States.

In the second part, we address how operators of wind power plants and power systems can incorporate advanced wind forecasting technologies into their operations, from a few days ahead planning to real-time operations. Wind power producers can take advantage of better forecasting methodologies by improving the accuracy of their bids into the market, thereby minimizing the penalties of not meeting their scheduled generation in real time. The financial costs and benefits will depend on the rules of the relevant market. For the system operator, advanced wind forecasting can help lower the uncertainty in the availability of wind power in real time, thus reducing the need to maintain operating reserves. In addition, reduced wind uncertainty will improve the system operator's ability to optimize the operation of the rest of the power plants in the system, including unit commitment, scheduling, and real-time dispatch. In sum, incorporating improved wind forecasting tools in the power system operation has the potential to reduce the costs of integrating wind power and therefore increasing the potential penetration of wind energy in the power system. We will develop improved methodologies and algorithms to incorporate the output of wind forecasts into decision support models for wind power plant and power system operation. An important objective in this is to engage the power industry in this activity. We are therefore establishing partners among wind power producers and power system operators, both in the United States and Europe.

2.2 WORK PLAN AND STATEMENT OF OBJECTIVES

The work plan is structured into a number of tasks for each of the two parts. The scopes and objectives of each task are outlined below.

2.2.1 Part 1 – Advanced Wind Forecasting Techniques

Under Part 1, we will survey existing wind power forecasting methodologies and tools and identify strengths and limitations of different approaches. We will develop a synthesis of various aspects that will prove useful from an end-user point of view for the selection and application of short-term wind power forecasting tools. We will also identify critical areas for improvement in existing methodologies. As part of our work, we will develop a consistent methodology for assessing the performance of wind power forecasting models. In the longer term, we will use the results from the assessment of current forecasting tools to develop an improved model for wind forecasting in the United States.

Subtask 1a – Wind Forecasting Data and Information Gathering

The objective of this subtask is to collect all available information related to state-of-the-art wind forecasting. We will give an overview on past and present attempts to predict wind power for single turbines or for entire regions, for time horizons ranging from a few hours to a few days ahead. The starting point will be a thorough literature review, taking into account the latest developments. We will also present the main results of other similar studies and experiences, synthesizing information about different innovative procedures and various applications, implementations, and case studies. We will pay particular attention to experiences in Europe.

Subtask 1b – Determination of Specific Needs for Wind Forecasting in the United States

The objective of this subtask is to study wind forecasting issues specific to the United States. In particular, we will focus on Numerical Weather Prediction (NWP) modeling and ensemble forecasting available for the North American geographical area. We will study the most important characteristics of the current set of NWP models available in the United States. We will also investigate the specification of guidelines for evaluating the accuracy of an NWP model. We will study ensemble forecasting to improve the accuracy of NWP models and to understand the reliability of the results.

Subtask 1c – Wind Forecasting Guidelines and Evaluation Benchmarks

The objective of this subtask is to create guidelines and recommendations for specifying requirements for forecasting tools, particularly oriented toward U.S. applications. We will describe the general requirements for a wind forecasting tool. An important requirement when evaluating wind forecasting tools is to have a set of criteria and benchmarks that can be used to compare different forecasting models. There is currently no overall consensus on what these evaluation benchmarks should be. We will therefore focus on developing a set of consistent evaluation criteria for different participants in the power system.

Subtask 1d – Wind Forecasting Report

A wind forecasting report will be developed to summarize the findings from subtasks 1a – 1c and present several important aspects of wind power forecasting technologies and applications. In particular, we will focus on trends emerging from recent experiences in Europe, including research projects, forecasting benchmark competitions, and application experiences. On the basis of our findings, we will provide comments and recommendations for improved wind power forecasting requirements and evaluation benchmarks for the United States.

Subtask 1e – Development of Improved Wind Forecasting Methods

Under this subtask, we will develop improved statistical short-term wind power forecasting methods on the basis of a new conceptual approach and new computational intelligence techniques that will enhance the performance of the current models. The systems will be designed for a forecast horizon of 72 hours to enable their use by system operators as well as wind power producers for electricity market bid offers and wind farm maintenance tasks. We will develop the forecasting methods based on integrated structures of statistical models that can be adapted to all wind farm characteristics and to the use of upstream forecasts from different

NWP models. Our wind forecasting systems will be based on a combination of wind-turbine (or wind farm) power curve models and dynamic models. Dynamic models use the latest values corresponding to wind farm power generation measurements to obtain the forecasts in the first hours. Our research will concentrate on approaches based on entropy measures instead of minimum square errors because they directly address the problem of non-Gaussian distribution of errors, as it has been demonstrated that the errors in NWP models are non-Gaussian. Furthermore, we will investigate models using on-line training with concepts from data streaming because wind behavior exhibits concept drift in the underlying probabilistic distributions. We will study different approaches concerning the representation of the power curve, as well as how the supervisory control and data acquisition (SCADA) system information is used. As experience has shown, a careful blend of different techniques appears to be the best approach. Finally, we will pay particular attention to the objectives of the model. So far, all wind power prediction models are formulated as a signal processing problem and evaluate predictions with mathematical error criteria. However, from an industrial point of view, different errors may have different costs, depending on the market rules. The choice of model objective will be closely related to the forecast evaluation benchmarks in subtask 1c.

2.2.2 Part 2 – Improved Methods and Practices for Wind Power Operation

In Part 2, we will address how operators of power systems and wind power plants can incorporate advanced wind forecasting technologies into their operations, from the planning taking place a few days ahead to real-time operations. For the system operator, advanced wind forecasting can help lower the uncertainty in the availability of wind power in real time and therefore reduce the need to maintain operating reserves. In addition, reduced wind uncertainty will improve the system operator’s ability to optimize the operation of the rest of the power plants in the system, including unit commitment, scheduling, and real-time dispatch. Wind power producers can take advantage of better forecasting methodologies by improving the accuracy of their bids into the market, thus minimizing the penalties of not meeting their scheduled generation in real time. In sum, incorporating improved wind forecasting tools in the power system operation has the potential to reduce the costs of integrating wind power and therefore increase the potential penetration of wind energy in the power system.

Subtask 2a – Establishment and Maintenance of a Consortium of Industry Participants

An important part of the project will be the involvement of electric power industry participants to evaluate and improve their current practice when it comes to wind forecasting and its use in day-to-day operations. We will establish a small consortium of companies, including wind power producers and system operators. The link to Europe is important for the project, since Europe has a longer experience in power systems with substantial shares of wind power than the United States.

Subtask 2b – Review of Current Operational Practices for Wind Power

Under this subtask, we will review and compare how wind power forecasts are currently taken into account in power plant and power system operations in the United States and Europe. This work will be performed in collaboration with the industry consortium established under subtask 2a. The review will include what types of wind power forecasts are being used (if any) and how the output from the wind power forecasts are taken into account in the operations. In particular, we are interested in identifying areas of improvement for how advanced wind forecasting methodologies can contribute to reducing the cost of integrating wind power into the system without compromising system reliability. The review will include unit commitment, day-ahead scheduling and bidding, ancillary services, and real-time dispatch. On the basis of experiences in the United States and Europe, we will develop a list of recommendations for improving the methodologies and practices currently being applied for these purposes.

Subtask 2c – Development and Testing of Improved Methods and Practices for the Use of Wind Power Forecasts in Power System Operation

Under this subtask, our objective is to develop improved operational methods and practices for handling large shares of wind power in the power system. Control room operators and independent system operators apply optimization methods for operating the system economically and efficiently while maintaining system security. The variability and uncertainty in wind power generation poses a major challenge for system operators in power systems with a large share of wind power.

On the methodological side, our approach will extend our previous work to simulate the intermittency and the volatility of wind in an operational security-constrained unit commitment (SCUC) model with network constraints. We will use the wind forecasting techniques developed in subtask 1e to prepare the hourly forecast of wind power. Then, we will consider the volatility of the forecast in the SCUC by simulating possible wind power volatility scenarios combined with load forecasting errors and other uncertainties, such as the availability of other generation units and transmission outages. We will use scenario reduction techniques to decrease the computational requirement for simulating a large number of scenarios. We will consider multi-stage stochastic programming to capture how uncertainty gradually unfolds over time. We will also investigate another option for accommodating the wind power volatility into system operations, that is, by allocating additional hourly reserves. In this case, to maintain the security of the system, reserves will be called instead of re-dispatching on-line units when the actual wind generation deviates from the forecast. Finally, an important component of this task will be to collaborate with the industry consortium to test advanced wind forecasting methods and their integration into operational practices for selected plants and systems. The consortium will be involved throughout the development and testing of new operational methods.

Subtask 2d – Use of Wind Forecasts for Wind Power Plant Operation and Bidding

We will investigate how advanced wind power forecasts can be integrated into the market bids of wind power producers. The optimal bids into energy, and possibly ancillary services markets, will depend on the physical characteristics of the wind power plants as well as the portfolio of power plants the company owns. In addition, the design of the electricity market may have an important impact on the wind power producers’ incentives and how to optimally bid and operate wind power plants in the marketplace. An important question is the trade-off between selling the wind generation in a long-term contract with a fixed price and selling in spot markets with higher price uncertainty. The availability of advanced wind forecasting techniques may influence the optimal hedging decision. This problem will be investigated in parallel with the development of the wind forecasting model in subtask 1e. We will also rely on input from the industry consortium in developing an analytical approach to address this problem.