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INSIGHT & COMMENTARY

The Role of Wind Forecasting in the Successful Integration and Management of an Intermittent Energy Source

Dr. Jeff Lerner
Director of Product Delivery, 3TIER

Michael Grundmeyer
Director of Financial Services, 3TIER

Dr. Matt Garvert
Director of Resource Assessment, 3TIER

Owing to the increased penetration of wind power, utility and system operators familiar with managing non-renewable power sources are being forced to learn new a new trade: wind forecasting. When the relied-upon fuel is inherently intermittent -- not a characteristic of traditional energy sources -- understanding the supply side of load balancing, dispatchability and reserves, and the cost of producing electricity inevitably becomes more challenging. This paper discusses how and why accurate wind forecasting is a necessary ingredient for the continued growth and penetration of wind power into the global energy mix. It is equally important to note the critical need for proper collaboration in planning the distribution and size of wind projects, and the electricity transmission grid from the municipal to international scale. Such efforts would require significant cooperation by parties spanning from industry, policy, education and research.



A wide range of variables are considered when evaluating the suitability of a potential wind energy project location. Site characteristics such as accessibility during construction, the distance to transmission and load can determine if a site is ideal for development. Clearly, for wind energy development, a site's meteorological conditions are of paramount significance, since wind acts as the fuel in wind energy projects. Even though the fuel is free, no amount of money can buy additional fuel once a project is built. Project siting is therefore the single most important, controllable factor in determining the economic viability of a wind energy project.

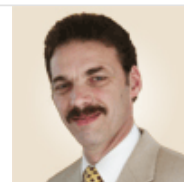
Because direct observations of wind speed are only taken at a limited number of sites, it is unfeasible to develop a comprehensive data set based on observations alone. To remedy this, computer simulations of the dynamics of the atmosphere (numerical weather prediction models or NWP) can provide vital spatial and high temporal information on the wind resources at a site¹. Proper assessment techniques using NWP modeling can provide valuable information on the expected diurnal and seasonal load for a project as well as a long-term evaluation of the site's potential.

Understanding Forecast Error

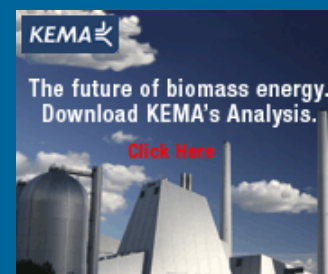
Assuming all turbines are always online and performing at their highest efficiency, a typical operational wind project will produce at approximately 30 percent of the potential capacity over a year based on the wind potential. In

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reality, several non-environmental factors exist that can diminish a project's output potential, many of which can be mitigated.

The absence of a wind power forecast at a site is a liability that will undoubtedly lead to lost revenues, especially as a project's lifetime progresses. For example, the forecast error associated with not having any knowledge of the future wind power generation (unskilled forecast) will likely exceed 40 percent of the plant capacity when verified against actual output. Figure 1 illustrates the magnitude of the forecast error as a function of the forecast lead time for a hypothetical 100 MW wind project. In this figure, three different forecasting approaches show the reduction in error using different methodologies for wind power forecasting.

Climatology represents the error associated with using a constant value forecast that is calculated from the average power produced for that project based on actual or reconstructed historical data. A persistence forecast utilizes the current power value to produce the constant power forecast for the rest of the forecast period (e.g., 50 hours in Figure 1). A more advanced forecast system is based upon the output of both statistical and NWP models that integrate project power or meteorological observations. Figure 1 illustrates that (1) the persistence forecast is not bad on average, particularly for the short-range period, and (2) forecast error, in general, increases with lead time, eventually approaching climatology.

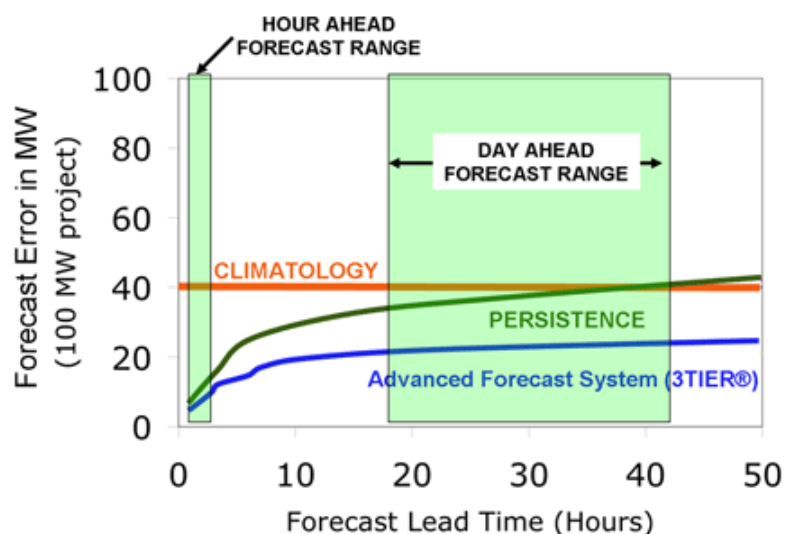


Figure 1: Forecast Error (MW) as a function of the forecast lead time (hours) for a wind power plant with 100 MW capacity. See text for explanation of climatology, persistence, and advanced forecast system.

The Business Case for Wind Forecasting

In an economic environment where every dollar matters, the fiscal consequences of not implementing wind power forecasts are felt more than ever. Project operating costs can unnecessarily balloon when energy providers are saddled with imbalance charges that result from deviations in their scheduled output. Wind power forecasts can help to minimize these penalties, but will not completely eliminate them. Wind power forecasts can also reduce the significant opportunity costs of being too conservative in bidding output into a forward market, due to uncertainty of availability.

Depending on the individual risk tolerance of the specific forecast user, prediction intervals can be incorporated into the decision making process for scheduling power production. The gray shading bounded by black lines in Figure 2 visually illustrates the concept of a prediction interval. The prediction interval encompasses the range of values where the hourly-averaged observation falls in a given percentage of the time, in this case 80 percent. The size of the prediction interval is determined by the historical forecast errors, which are a function of the forecast hour and the value of the forecasted power and wind speed (Meade and Islam 1995). In Figure 2, forecast power values (thick orange line) display

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different prediction intervals in time: the 21-hour forecast at Tuesday 0300 prediction interval [labeled "(a)"] spans about 15 percent project capacity whereas by forecast hour 84 [Thursday 1800, labeled "(b)"], the interval range is over 40 percent capacity. A sharp prediction interval conveys more forecast certainty and could result in less conservatism and lower opportunity costs concerning an energy bid. In general, as the wind power forecast becomes less certain for a longer term forecast, the width of the prediction interval increases. Figure 2 illustrates the imperative nature of accurately interpreting the expected forecast errors and using this information in decision-making processes such as energy scheduling and electricity trading, prices can be directly correlated to the output of wind power.

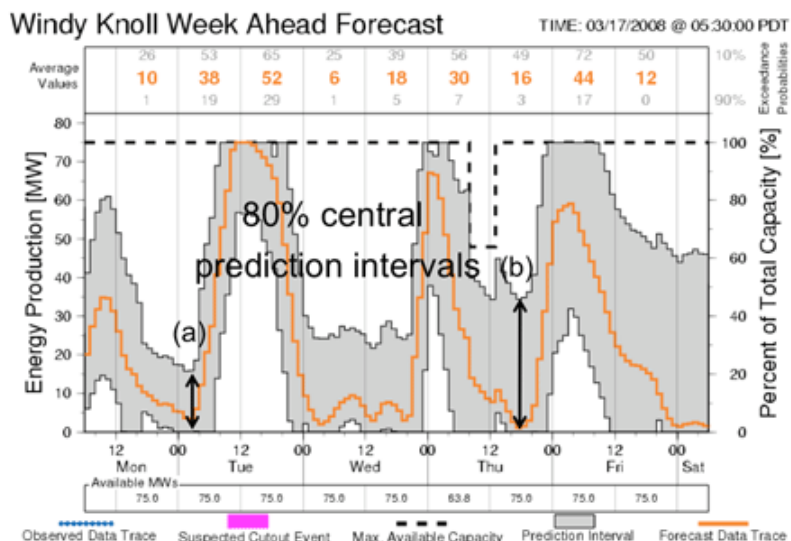
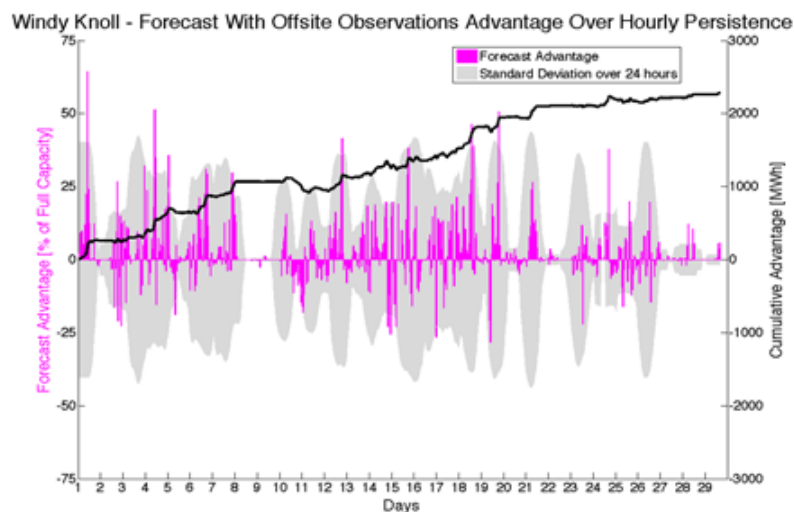


Figure 2: Week ahead forecast for wind project with 75 MW capacity. The grey shaded area is between the 90 percent and 10 percent exceedance probability values. The thick black dashed line is the wind project scheduled capacity. The orange line represents the P50 or value where the forecast has an equal probability of exceeding or being less than.

Accurate forecast information provides undeniable value to grid operators, energy traders and maintenance schedulers through its direct cost-saving implications which are only magnified over time. By employing advanced forecast information, the realized cost savings accumulate over periods of time when compared to using a non-skillful approach such as persistence or climatology. In Figure 3, the accumulated savings, in MWh, is summed over a 30-day period. In this example for a 100 MW capacity wind project, this equates to over 2000 MWh savings by simply using the forecast at face value. Assuming a wholesale price of \$0.05/KWh, one could create a monthly savings of \$100,000 when utilizing a skilled forecast in place of persistence methods.



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Figure 3: The forecast advantage expressed in percent of full capacity for a 100 MW wind energy project. The solid black line is the cumulative advantage (MWh), the gray shading is the standard deviation of the forecast (%), and the pink bar is the forecast advantage (%) of using an advanced forecast system over that of using a baseline hourly persistence forecast over a 30-day period.

Fluctuating electricity prices and load imbalances frequently result in the scaling back of wind energy, particularly in several regions of the country where the electricity transmission infrastructure has not been updated to manage the input and magnitude of variable energy sources. However, the frequency and length of curtailments often has to do with underutilizing the information contained within a wind energy forecast. Advanced knowledge of expected surges in cheap and clean wind energy production allows grid operators to reduce costs through the power-down of more expensive natural gas-fired plants. Much of the unpredictability associated with electricity bottlenecks are being addressed by increasingly common region-wide wind power forecasts which are available through forecast service providers. Regional wind power forecasts also include an added benefit through the reduction of the overall forecast error as individual wind project forecast errors tend to cancel each other.

Direct cost savings can also be induced by the use of forecasting when operators schedule wind project maintenance and construction. Wind projects often require that turbines be taken down during the commissioning of new turbines, a time-intensive activity that can take hours to weeks to complete. Precipitation, high winds and extreme temperatures need to be avoided for obvious reasons. Without accurate forecasting information, the chances of idling a mobilized work crew and necessary equipment (such as large cranes) increases. The associated costs can exceed \$10,000 per day. If these activities aren't tasked in the right weather conditions severe financial implications can result. Project costs increase as deadlines are not met, plant generation is diminished, and resultant production revenues from Green Tags or Production Tax Credits are lost.

Wind Power Forecasting's Horizon

No longer a novel capability or tool, utility-scale wind power forecasting has seen great advancements in quality, timeliness and delivery of the forecast product. However, hurdles do loom for the wind power industry and the science behind the forecasts (see Table 1). As the forecasting industry progresses and grows, short-term wind power forecasts will improve from longer historical forecast records and additional observations. Further, implementation of NWP model ensemble forecasts has enormous potential in reducing error that isn't currently being fully exploited for the short- to long-range forecast. To ensure both the continued improvement of accurate forecasting capabilities, as well as a healthy pipeline of renewable energy integration, the continued collaboration and cooperation of industry, governments and educational institutions must occur.

Table 1: Current and future challenges to forecasting wind power

- **Making accurate very-short range (less than 60 min.) forecasts**
- **Improving ramp event predictions**
- **Incorporating climate change impacts on wind projects**
- **Integrating and automating regional forecasts with electricity scheduling systems**
- **Improving icing forecasts**
- **Improving probabilistic forecast product development using NWP ensembles**

It has been shown that forecasts of wind power are closer to actual wind power production when utilizing a more advanced forecast product that utilizes state-of-the-art Numerical Weather Prediction models. Statistical methods (such as Artificial Intelligence models) incorporate project power and nearby observations

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for more accurate short-range forecasts than what could be obtained from persistence alone. The implications of the value of the forecast are: reduced imbalance charges and penalties; competitive knowledge advantage in real-time and day-ahead energy market trading; and more efficient project construction, operations, and maintenance planning. Accurate wind power forecasts are also important in reducing the occurrence or length of curtailments which translate to cost savings, improved worker safety and mitigating physical impacts of extreme weather on wind power systems.

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1. See <http://firstlook.3tier.com> for detailed information on wind resources
2. Meade, N. and T. Islam, 1995: Prediction Intervals for Growth Curve Forecasts, *Journal of Forecasting*, 14, 413-430.



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