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# Improving The Economics Of Wind Through Forecasting

*Project generation variability and the implications of longer-range predictions need to be better understood.*

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In the next 15 to 20 years, the installed wind energy capacity in the U.S. can be expected to increase to 100,000 MW. This level of wind energy development represents a penetration rate – the total amount of wind as a percentage of total electricity generation – of more than 6%, nearly two-thirds of the amount that is currently generated by hydropower.

Even greater wind energy penetration projections are proposed by many for Canada, and certainly the resource is there to support the projections.

When this level of wind energy penetration is considered within the context of a geographically asymmetrical resource (and the resulting asymmetrical development), coupled with the physical and economic constraints of the transmission system, some regions will undoubtedly have wind penetration levels in excess of 20%. The limited ability to move power into or out of these regions is expected to continue.

While the development of additional wind energy projects is indeed desirable – certainly from energy security and environmental stewardship perspectives – higher wind energy penetration rates introduce new challenges and uncertainties to the electricity generation and transmission system. Planning for and confronting these challenges will result in a more efficient electrical generation system that can successfully and reliably integrate more wind generation.

The objective of this article is to outline some of the challenges to consider, from a forecasting and resource availability perspective, as wind energy becomes a larger portion of North America's electricity generation mix. A months-ahead wind energy forecasting strategy – based on climate forcing – with an ability to predict departure from normal (DFN) wind energy production is also described.

### Framing the challenge

While wind is an inexhaustible, virtually free energy resource, it does have the complicating characteristic that it is highly variable, in both place and time. This characteristic certainly affects the integration of wind, and is arguably one of the greatest challenges of wind energy.

At the individual-project scale, wind integration is seen primarily as a shorter-range operational issue, with the greatest challenges at the minute-, hour-, to day-ahead time horizons. Regulation, load following, asset allocation and transmission scheduling are some of the issues for the operational integration of wind, especially at the single-project scale.

But as we begin to look at wind energy generation from the perspective of multiple sites over broader geographic regions – basically a systems perspective – additional issues begin to appear. While geographic dispersion of wind projects in a given region can help considerably to attenuate the intra-hour and intra-day volatility of integrating multiple wind projects, it has less of a smoothing effect over longer time periods. This is because the geographic scale of climate phe-

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nomena that can positively or negatively impact wind energy production often covers broad geographic regions (over a scale of tens to hundreds of kilometers).

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Therefore, the effects due to oscillatory shifts in climate can be expected to be similar at many projects within a transmission control region for periods ranging from weeks to months at a time. As wind energy penetration rates increase into the tens of percent in some regions, these temporary swings in climate – and the effect they have on wind energy generation across these regions – will have to be planned for, in order to maintain cost effectiveness and ensure electricity reliability.

### Lessons from hydropower

The value, both from an economic as well as a reliability perspective, of extended wind energy forecasts has not been fully assessed within the wind industry. One only has to look at the most utilized weather-driven renewable energy in the world – hydropower – as an example of the value of knowing, to some degree, months in advance the anticipated generation.

Within the hydropower community, extended streamflow prediction (ESP) is readily accepted and widely used. These long-range forecasts, often expressed as a monthly deviation from normal conditions, are used for a number of issues, ranging from the optimization of water released from reservoirs, to the selling (or buying) of electricity in forward markets, to increase revenues (or decreased losses) from anticipated excesses (or shortages) in generation.

While the similarities are there, important differences exist between the long-term availability of hydropower and that of wind.

First, the characteristic time-scale of intermittency between wind and hydropower is different. The volatility of both wind and hydropower at two important time scales: the intra-day and the inter-month were compared. This comparison reveals that wind has much greater volatility at the intra-day time scale (expressed in deviation in capacity factor), but considerably less volatility than hydro over inter-monthly time scales.

This lower volatility of wind over longer time periods – which is obviously advantageous from a seasonal risk perspective – has to be tempered with the fact that, unlike hydro, which can often be stored in reservoirs for anywhere from hours to months, wind energy cannot be stored.

This requirement to integrate wind energy immediately into the system certainly shifts the response from one of changing operations at the project level to either a multi-asset re-allocation strategy, such as the allocation of hydro or thermal assets (and the associated purchase of fuels for the thermal projects) to provide additional generation, or a financial hedging strategy, such as the securing of long-term contracts for anticipated shortages in electricity.

So while there are analogies between the value and utility of long-range forecasts for wind and hydro, the operational and strategic responses to these forecasts will likely be different, and will be a function of both the generation portfolio as well as the responsibilities of the forecast user.

### Long-range predictability

The atmosphere is an extremely complex and dynamic system. It is very difficult to accurately predict the weather more than one week in advance. In fact, the theoretical limit of deterministic weather forecasts – the forecasting of specific weather events – is only about two weeks.

Climatology, however, helps to explain what is likely to occur on a given day or group of days well into the future, based on a statistical analysis of past weather. Since the atmosphere responds to a number of boundary conditions that can be discerned at the time a forecast is made, it is possible to identify a shift in the most likely scenario for a given year to either a wetter, drier or windier condition than the climatological average, for example.

Perhaps the most studied, measured and useful atmospheric boundary condition for assessing temporary shifts in the North American climatology is the sea surface temperature of the equatorial Pacific Ocean.

During some years, the water in a vast region of the equatorial Pacific Ocean is warmer than normal, and in other years it is cooler than normal. The oscillation between the warm and cool conditions is known as the El-Nino Southern Oscillation (ENSO), and the warm and cool phases are referred to as El-Nino and La-Nina, respectively.

The global atmosphere responds to these ocean temperature anomalies, and the response is varied by region. These ocean-weather relationships are so strong, and the value of predicting the ENSO cycle is so great, that several networks have been established to monitor the ocean surface temperature. The relationship between ocean temperature anomalies and weather has clear implications for wind energy. This is because in many geographic regions, wind energy production is tied to the mean location of the jet stream, and the mean location of the jet stream is affected by shifts in ENSO.

The main obstacle to demonstrating this linkage is the absence of long-term, high-quality records of wind speeds at currently operating or proposed wind energy projects. Since a single ENSO cycle can last for three to five years, several decades of wind speed data are required to determine the long-term variability in monthly, seasonal and annual wind energy production from a project.

### *A forecasting system*

Recent increases in computer speed and high-capacity computer storage devices, as well as advances in weather simulation models, have facilitated the development of new methods for estimating the variability in wind. 3TIER Group has leveraged these advances to develop a comprehensive renewable energy assessment methodology referred to as a Resource Related Risk Analysis (R-cubed). The technique uses numerical weather-simulation models, statistical algorithms and supplemental models to integrate global archives of weather observations, high-resolution land surface and terrain data, and project-located measurements to simulate the past meteorology (i.e., weather) that occurred at a particular project.

With the addition of an actual or proposed wind energy power curve, this technique can provide an hourly time series of historic power production, extending over decades, at any location on earth, providing valuable information on the economic viability of a proposed project before the project is built. A 40-year R-cubed analysis was done for a wind project being developed for Puget Sound Energy in the Pacific Northwest U.S.

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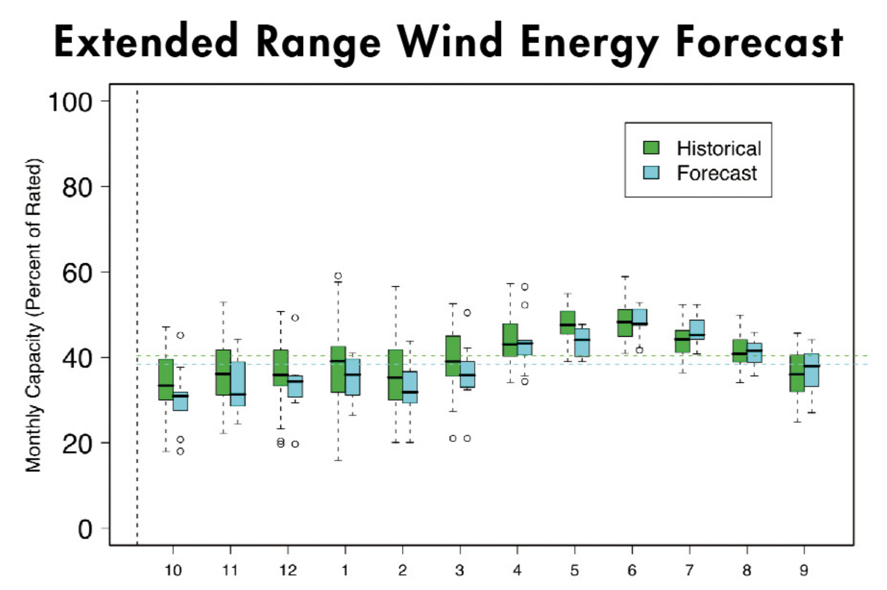
Using the R-Cubed analysis as a foundation, and coupling it with forecasts of ENSO and other climate oscillations, 3TIER has developed a system for predicting wind energy generation several months into the future. Just as is done for hydropower, forecasts are made for the expected DFN, but now for wind energy production rather than reservoir inflows.

The winter of 2004/2005 serves as an example for the development of a months-ahead DFN forecasting technique for wind energy. As early as September 2004, many of the major climate forecasting centers were forecasting the development of a mild El Nino in the equatorial Pacific. This forecast proved to be correct, with a mild El Nino forming by late summer of 2004 and lasting until early winter of 2005. The winter of 2004/2005 proved to be one of the driest and warmest on record in the Pacific Northwest, and the lack of storm systems caused a significant reduction in the overall wind energy production during the winter.

Figure 1 shows a months-ahead DFN forecast for wind energy output for the period from October 2004 to September 2005. The left green boxplot of each pair is the historic distribution of capacity factors taken from the full record – from the R-cubed produced climatology – from 1965 to 2004 (sample size of 40). The right cyan boxplot is the forecast. As a consequence of the forecast for an El Nino winter, the forecast is clearly for below-average wind during the winter months.

For example, the historic distribution of capacity factor for February from 1965 to 2004 suggests a median of approximately 35%, with a maximum and minimum of roughly 55% and 15%, respectively. The forecast for February clearly shows a lower median – a capacity factor of approximately 30% – with a maximum and minimum of roughly 45% and 15%, respectively. A similar decrease in expected wind energy is noted for all the winter months of the forecast period (October to March). As was predicted using this method, the observed wind energy production during the winter of 2004/2005 in the Pacific Northwest was significantly below normal.

**Figure 1**




**Depicted is a simple months-ahead forecast for the combined output of three projects considered for development in the Pacific Northwest by Puget Sound Energy.**

### *Summary and conclusions*

This article presents the challenges, anticipated benefits, and a methodology for producing months-ahead wind energy forecasts. Significant increases in wind energy penetration in future years will place a greater importance on long-range forecasts.

Analogies drawn from hydropower – another weather-dependent and intermittent resource – underscore the importance of longer-range forecasts for effective planning and decision-making, although the actual responses to these forecasts may be different due to characteristic differences between wind and hydropower.

The described forecast method combines long-term retrospective analysis of the month-to-month variability of a project's wind resource with the traditional approach of forecasting based on analog years. Given the retrospective data, a number of refinements to this simple approach can and are being made, but even the simple analog method predicted the 2004/2005 winter wind drought in the Pacific Northwest several months in advance. NWP