VARIABILITY AND PREDICTABILITY OF LARGE-SCALE WIND POWER

Wind power is generated by wind speeds that vary continually. This creates generation that is constantly fluctuating. The variations of wind power are smoothed as many wind turbines are aggregated in a power system. Aggregating many wind power plants will also improve the accuracy of forecasting output. Forecast accuracy is reasonable hours ahead, but will decrease for days ahead horizon. Forecast systems can also provide information about the uncertainty.

How much variability is there in wind power?

A single wind turbine can shut down from full power in seconds, and also start up during high winds very quickly. However, the aggregated output from hundreds or thousands of wind turbines in a power system area will be fluctuating more smoothly (Figure 1). The second and minute fluctuations will smooth out with increasing number of turbines. The hourly fluctuations will also diminish when the wind power plants are distributed several hundred kilometers apart.

The variability of large scale wind power depends on the variability of the wind resource, and how dispersed wind power plants are located within the area. Generally speaking, the hourly step changes from large-scale wind power are usually within ±10% of the installed capacity – in larger areas even within ±5%. This means that with 10 000 MW of wind power the changes are rarely more than 500 MW or 1 000 MW in one hour. This should be compared with changes in electricity consumption. For a power system that has a peak load of 43 000 MW (Spain) consumption can change more than 3 000 MW in an hour, typically once a day.

Wind power changes in 15 minutes or 5 minutes are less than changes in one hour.

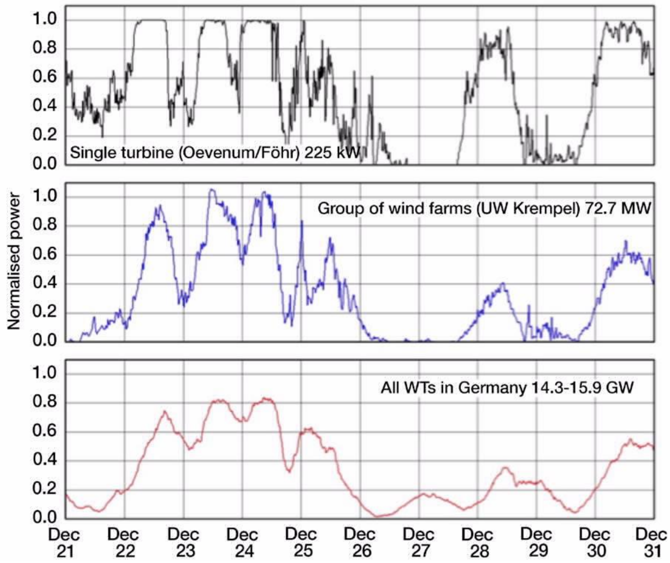

Figure 1. *Aggregated generation from multiple wind power plants is a smoother curve than that of a single turbine. The minute and hour changes are smaller, and also the range will be reduced, not reaching full installed power from all turbines simultaneously. As seen in the middle plot, the generation of wind power from a small area can sometimes exceed the installed capacity. (Source: Task 25 summary report, 2009)*

How large can wind power ramps be?

In extreme situations, the change from one hour to another can be more than 20% of installed wind power.

The most extreme case is a storm, where wind speeds exceed 20-25 m/s and wind turbines shut down from full power to protect the structures.

However, storm fronts usually take several hours to pass a region that covers several hundreds of kilometers. For large scale wind power this will be seen as a decrease in total power output lasting for 2-6 hours. Such severe storms do not occur every year in all countries, but in storm prone areas there can be several storms in one year.

How accurately can wind power generation be forecasted?

To predict wind power for more than a few hours ahead, wind speed forecasts from weather-prediction models are used. Wind energy forecasting has been evolving since the 1990s and is still progressing. The overall shape of wind generation can be predicted one day-ahead (Figure 2). Significant errors can still occur from time to time in both the output level and timing of wind squalls – for example predicting that winds will start blowing at 10 am when they only start at noon. Wind forecast accuracy improves for shorter time horizons. There is a strong aggregation benefit for wind forecasting; aggregation of many wind power plants over a 500-km region reduces forecasting error by about half (Figure 3).

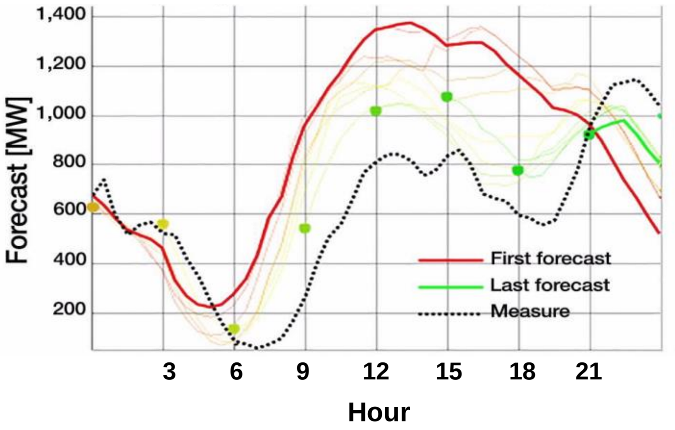

Figure 2. Short term forecasting of wind power generation, example showing how forecast accuracy improves with shorter forecast horizon. The first forecast 24 to 48 hours ahead in red, last forecast 6 to 30 hours ahead in green and measured power in black. (Source: Hydro Quebec)

Today there are also forecast systems that provide additional information about the forecast uncertainty (Figure 4). These forecasts are also able to warn of a possibility for extreme forecast errors that may impact power system stability.

The variability of solar power on partly cloudy days has similar challenges as those of wind power – and also similar aggregation benefits to smooth out variability and improve forecast accuracy for larger areas. Solar energy for sunny or uniformly cloudy days are easier to forecast than wind energy. However, the morning and evening ramps will challenge the power system operation at higher shares of solar energy, even if forecasted right. Combining wind and solar brings benefits for system operation, as the total generation is smoother.

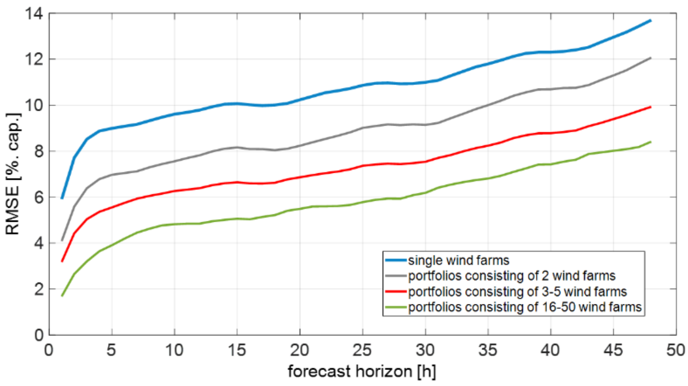

Figure 3. Example of aggregation benefit on wind energy forecast error. The average error is increasing as the time horizon to forecast increases. When wind power plants from larger area are aggregated the errors are less, in all time horizons. The curves represent the quality of single wind farms and of wind farm portfolios with different sizes. (Source: Dobschinski, 2014)

Associated publications

- Dobschinski, J. (2014, Nov.). **How good is my forecast? Comparability of wind power forecast errors**, 13th Wind Integration Workshop, Berlin. Energynautics.
- Kiviluoma, J. et al. (2016). **Variability in large-scale wind power generation**. Wind Energy, 19(9), 1649–1665. https://doi.org/10.1002/we.1942
- Holttinen, H. et al. (2019). **Design and operation of power systems with large amounts of wind power**. Final summary report, IEA WIND Task 25, Phase four 2015–2017. https://community.ieawind.org/task25/ourlibrary
- Bauer, P.; Thorpe, A.; Brunet, G. (2015). **The quiet revolution of numerical weather prediction**. Nature, 525, 47–55. https://doi.org/10.1038/nature14956

More information

This Fact Sheet draws from the work of IEA Wind Task 25, a research collaboration among 18 countries. The vision in the start of this network was to provide information to facilitate the highest economically feasible wind energy share within electricity power systems worldwide. IEA Wind Task 25 has since broadened its focus to analyze and further develop the methodology to assess the impact of wind and solar power on power and energy systems.

See our website at
https://community.ieawind.org/task25

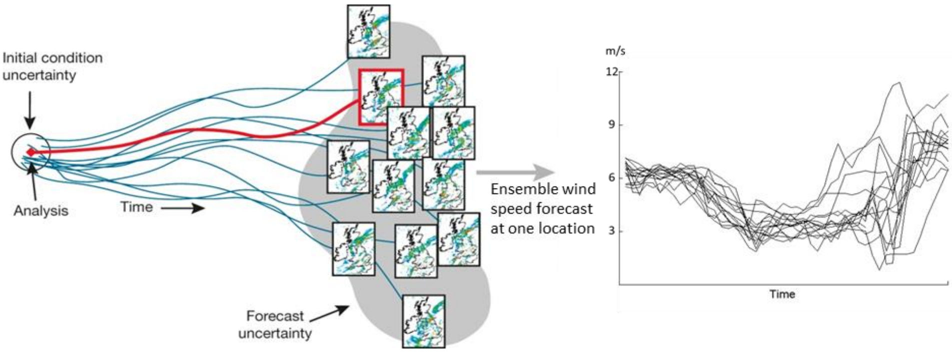

Figure 4. Illustration of a generation of an ensemble weather forecast based on varied initial conditions (left, based on Bauer et al., 2015).

See also other fact sheets

Storage and Wind Power Fact Sheet
Capacity Value of Wind Power Fact Sheet
Balancing Power Systems with Wind Power Fact Sheet
Wind Integration Issues Fact Sheet
IEA Wind Task 36 Wind Power Forecasting: http://www.ieawindforecasting.dk/