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Predicting Sudden Changes In Wind Power Generation

The varying sets of challenges that accompany ramp-event forecasting are dependent on the nature of the weather event causing the ramp.

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The ability to predict sudden, significant changes in wind power generation is emerging as a top priority for grid managers. In most cases, forecasts of hour-by-hour generation over the next day – or two – solve the grid operator's wind integration problem. However, an unforeseen ramp-up or ramp-down in generation – so-called ramp events – can leave operators scrambling to balance supply and demand while inducing substantial costs.

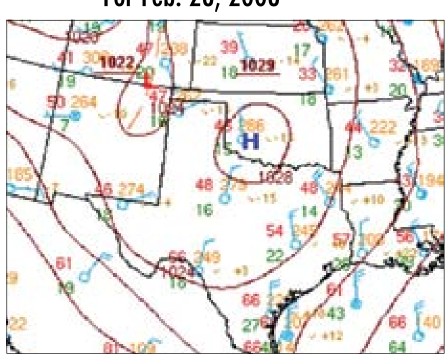
There are varying sets of challenges that accompany ramp-event forecasting, each dependent on the nature of the weather event causing the ramp. Some challenges are manageable, while others require more research and experimentation with untried techniques before an acceptable solution is found.

Ramp events can be forced by weather features, such as synoptic-scale (i.e., larger-scale) areas of high and low pressure. An example is the Feb. 26 fall-off of generation experienced in the Electric Reliability Council of Texas (ERCOT) footprint. The weather map in Figure 1 shows a large but weakening volume of high pressure settled across the southern Great Plains states.

Such large-scale weather phenomena with longer life cycles are easily resolved and predicted by state-of-the-art numerical weather prediction (NWP). In the case of the ERCOT event, the high pressure is coincident with the cooling and stabilizing of the lowest layer of the atmosphere as daytime heat is lost after sunset. As a result, there was a considerable reduction of wind in a two-hour period.

A wind power forecasting service that was being used non-operationally at the time predicted the event with a high level of accuracy. This forecasting service performed accurately under the type of weather regime being experienced at the time. Figure 2 shows how the actual generation (blue line with diamonds) stayed above the 80% probability of exceedance forecast (green line with triangles) and near the 50% probability of exceedance forecast (red line with squares) as it should have. Schedules from the market participants (gray line with squares) did not perform as well.

Figure 1: Midday Weather Map For Feb. 26, 2008



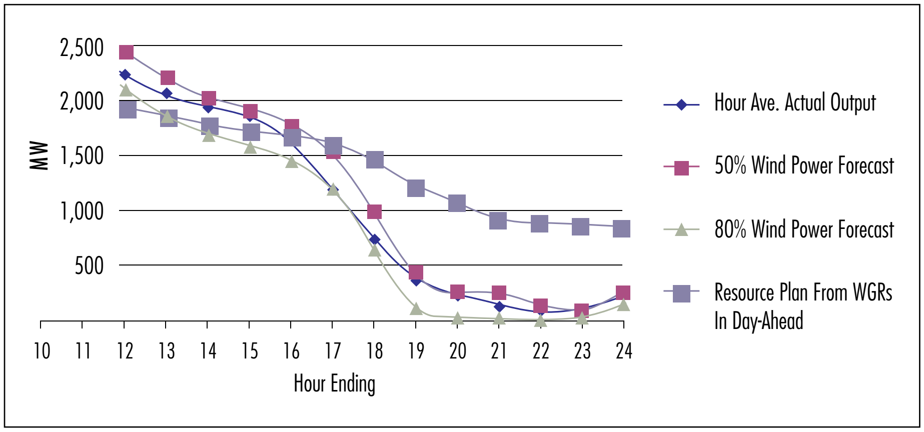
Surface high pressure cresting over northern Texas caused a sharp but predictable drop-off in wind later in the evening.
Image courtesy of AWS Truewind

Another type of event for which NWP becomes the most heavily weighted tool within a state-of-the-art wind power forecasting system is the passage of a cold front and the occasional surge in wind associated with rising barometric pressure and the advection (i.e., horizontal movement) of colder, denser air.

In such a case, meteorological or power generation data from the wind plant – data that is sought by a forecast vendor – is a poor predictive tool, as it gives no indication about what kind of weather is heading toward the site. While NWP is the preferred tool for this situation, such frontal passage events are subject to phase errors by the models (i.e., the real-world change in wind velocity often occurs sooner or later than predicted).

However, the use of mesoscale NWP in a rapid update cycle mode – a technique used where weather model runs are executed once every three hours, covering the subsequent six to 12 hours – together with off-site meteorological data (e.g., data from National Weather Service weather stations) may be an effective tool in

Figure 2: Wind Power Forecast: Feb. 26, 2008.



Courtesy of ERCOT

this case. This approach can greatly reduce the phase errors with each subsequent model run and fine-tune the amplitude prediction.

A significant change in power generation borne from large-scale weather features may be effectively predicted by weather models; however, smaller-scale weather features with shorter life cycles can be more problematic. Strong winds produced by a thunderstorm cluster can be considered as an example. While it is possible to model such a feature (represented in Figure 3) with high-resolution, mesoscale NWP, accurately predicting the precise characteristics of the feature is highly unlikely.

In Figure 3, the radar site is the black circular void immediately north of Sioux Falls. Green sections represent air moving toward the radar site, and red sections represent air moving away. The bright green sections southwest of the radar site (just east of Parker) show a strong wind field that is roughly eight kilometers in horizontal scale.

It is very unlikely that a weather model would be able to predict this feature with a level of accuracy meaningful to a grid manager. Even if the NWP being employed correctly predicts the development of a large thunderstorm cluster, there is a good chance the model will handle the evolution and timing of the feature poorly and incorrectly predict the velocity of the thunderstorm winds. Thus, predicting ramps in power generation borne from such a feature is extremely difficult.

Some ramp events are caused by vertical processes in the atmosphere. For example, if a wind plant lies within a cold, stable airmass, winds at turbine-hub height may be light, while winds 100 meters higher may be quite strong. If the atmosphere is allowed to mix vertically – a process that is common when the sun's radiation warms the lowest level of the atmosphere – the stronger wind resource aloft will be realized eventually, as upward and downward currents in the atmosphere transfer the wind energy down to the plant.

Such a diurnal, cyclical process may be well-predicted by climatology or statistical methods. Other cases may be very difficult to predict, such as cases in which a nocturnal jet – a wind phenomenon commonly experienced in the Plains – flows above a wind plant only partially covered by a stable layer, and the turbine blades are allowed to experience the stronger winds from time to time through sporadic mixing. In this case, numerous ramps may be experienced over a period of several hours.

Finally, ramp events may be the result of wind turbine cut-out, where winds reach the cut-out threshold of the turbine model, resulting in the immediate reduction of power generation for either all or some of the generators within a wind plant. Arguably, this is the most feared and difficult scenario to predict, and it could be the result of a smaller-scale weather feature, such as a thunderstorm complex, or a larger-scale feature, such as extreme wind flow between a region of high and deep low pressure.

In either case, when winds flirt with cut-out speed, a very small change in the wind speed can take power generation from plant capacity to zero and back again over a sub-hour interval. Consider a plant filled with turbines that cut out at 25 meters per second. Now, consider a forecast that calls for wind speeds between 23 meters and 26 meters per second over a one-hour time interval.

How does the forecasting system translate that into power prediction? What percentage of turbines will cut out during that time and for how long? What if the forecast is off by one meter per second? Certain cut-out events and resulting reductions in power generation can be extremely difficult, if not impossible, to predict, at least with current forecasting methods.

Significant ramp events are relatively rare, but an effective forecasting solution for that handful of hours each year may mean more to a grid manager than does the general forecasting solution for all the remaining hours. Solutions to the problem vary dramatically, and there is no one solution that fits all ramp cases.

In some instances, a deterministic forecast of wind power generation can be produced with an acceptable level of accuracy. In the previously noted example, a spike in wind associated with a cold, winter airmass surge can be predicted with rapid update cycle NWP supplemented with off-site, upstream meteorological data. This forecasting system configuration would incur a higher cost, given the added computational efforts of the update cycle, but the cost may be justified if the forecast user is sensitive enough to such an event.

In other instances, such as a spike in wind associated with wind outflow from a large thunderstorm, a probabilistic forecast is needed. As mentioned previously, a single thunderstorm exists on a time-and-space scale that is too small to be modeled effectively by current NWP techniques, and a deterministic forecast covering such an event could not be reliably produced.

Still, the grid operator needs information to manage such an event. In this case, a probabilistic forecast could flag the event for a grid operator. Real-time radar data coupled with state-of-the-art pattern recognition techniques in conjunction with warnings from local National Weather Service offices are tools that could be used to generate such a probabilistic forecast. Instead of a power generation forecast, the user would receive the probability of exceeding a certain threshold; in this case, a change in generation over a given amount of time.

A cutting-edge ramp-event forecasting service may feature an awareness element that could guide the user toward realizing the event's cause, whether it is a drop-off in power generation due to winds reaching cut-out speed from a large thunderstorm complex or a spike in generation from the passage of a strong autumn cold front.

The tools needed to produce this level of forecast sophistication have either yet to be perfected or yet to be developed, but they will be. Operators of power grids and large wind power generator fleets have spoken at wind energy and utility conferences alike, and the demand is clear – produce forecasts designed to predict significant swings in wind power generation and give operators better tools to aid in balancing these swings in the real-time market or scheduling reserves in the day-ahead market. NWP

Figure 3: Doppler Radar Representation Of Strong Outflow Winds Associated With Thunderstorms

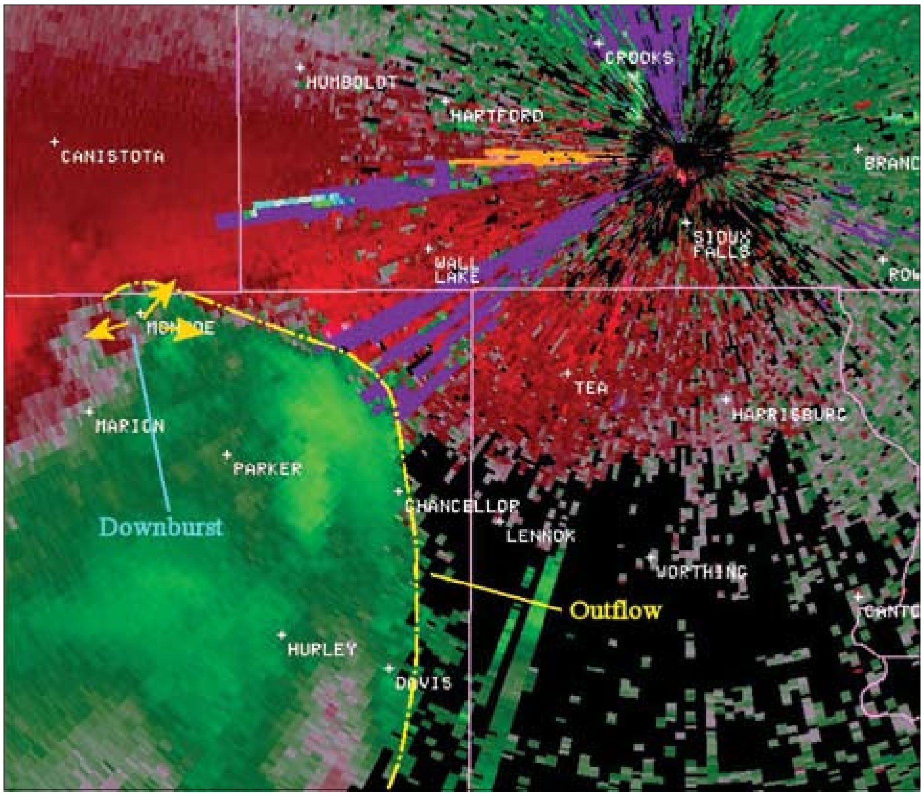


Image courtesy of National Weather Service Weather Forecast Office, Sioux Falls, S.D.

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