WIND ENERGY FORECASTING

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Wind Forecasting in the US

- Southern California Edison: 2000
- California ISO: 2004
- Electricity Reliability Council of Texas: 2008
- Midwest ISO: 2008
- PJM: 2009
- Bonneville Power Administration, Xcel Energy, others under development

*The great majority of US wind plants are now receiving forecasts*
Why Do Wind Forecasting?

- Unforecasted wind fluctuations increase requirements for spinning reserves and raise electricity system production costs.
- Unforecasted large ramp events can affect electricity system reliability.
- State-of-the-art forecasts have high economic value compared to their cost (but potential savings are not always realized).
- Wind forecasts become essential for effective grid management with high wind penetrations (>5%).
Cost of Intermittent Wind

Arizona Public Service (Acker et al., 2007)

Typical range for all studies: $1.5-$4.5/MWh

Roughly 2.5-7.5% of cost of energy
The Forecasting Challenge

If you think ordinary weather forecasting is challenging...

- Wind is typically created by small pressure gradients operating over large distances: hard to forecast accurately
- Turbulent & chaotic processes are also important & even harder to forecast
- Local topography can have a strong influence, but not captured in standard weather models
- Plant power curves are highly non-linear, so small errors in wind = big errors in power
- Plants experience unexpected losses and downtime and may operate sub-optimally
Forecasting Systems

- Weather observations set the initial conditions – but there is never enough data.
- Numerical weather prediction (NWP) models forecast evolution of weather systems.
- Statistical models convert wind to power output and correct for systematic biases and error patterns.
- Actual plant production data provide feedback to improve the statistical models.
- Forecast providers use these components in many different ways.
NWP Models

• Physical equations of the atmosphere are solved on a 3-D grid

• Initial conditions are obtained from observations (surface, balloons, satellites, Doppler radars, etc.)

• Models typically run 2x or 4x per day out 1-5 days

• Some forecast providers rely on government-run models; others run their own
Statistical Models

- Correct for systematic NWP biases & sub-gridscale effects
- Incorporate recent data from the site or nearby locations
- Often include conversion of forecasted winds to plant output
- Many different statistical models are used: linear regression, neural networks, support vector machines...

\[ F = f(P_1, P_2, ...) \]

Predictors

Predict and

Training Algorithm

SMLR

ANN

SVM
Forecast Time Horizons

• 5 - 60 minutes
  – Uses: Regulation, real-time dispatch decisions
  – Phenomena: Large eddies, turbulent mixing transitions
  – Methods: Largely statistical, driven by recent measurements

• 1-6 hours ahead:
  – Uses: Load-following, next-operating-hour unit commitment
  – Phenomena: Fronts, sea breezes, mountain-valley circulations
  – Methods: Blend of statistical, NWP models

• Day-ahead
  – Uses: Unit commitment and scheduling, market trading
  – Phenomena: “Lows” and “Highs,” storm systems
  – Methods: Mainly NWP with corrections for systematic biases

• Seasonal/Long-Term
  – Uses: Resource planning, contingency analysis
  – Phenomena: Climate oscillations, global warming
  – Methods: Based largely on analysis of cyclical patterns
How is Forecast Skill Measured?

- Typical: mean error (ME), mean absolute error (MAE), root-mean-square error (RMSE)
- More refined “skill scores” are sometimes used, e.g.
  - Improvement over persistence, climatology, or other “dumb” forecast
  - Skill at predicting special conditions, e.g. ramp events, max/min output, cumulative output in critical periods
- Skill scores should be customized to the user’s cost or risk function (but rarely are)
Typical Forecast Performance

"Hour-Ahead" Forecast

- eWind
- Persistence

- eWind v. Persistence

Mean Absolute Error vs. Forecast Hour

Skill Score vs. Forecast Hour

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Typical Forecast Performance

"Day-Ahead" Forecast

Mean Absolute Error vs. Forecast Hour

- eWind
- Persistence
- Climatology
- eWind v. Persistence
- eWind v. Climatology

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Apples and Oranges

• **Forecast performance varies with many factors**
  – *Forecast time horizon* (especially for short-term)
  – *Amount and diversity of regional aggregation*
  – *Quality of generation & met data from the plant*
  – Distribution of wind speeds relative to the power curve
  – Type of wind and weather regime
  – Shape of the plant-scale power curve
  – Amount of variability in the wind resource
  – Sensitivity of a forecast to initialization error

• **These factors make casual comparisons of forecast performance very difficult and lead to misconceptions**
How to Improve Forecasts

(3) Improved models
  ✓ Improved NWP modeling of sub-grid and surface processes
  ✓ Improved statistical models and training methods

(2) More effective use of models
  ✓ Higher resolution, more frequent NWP model runs
  ✓ Better data assimilation techniques
  ✓ Ensemble forecasting

(1) More and better weather data
  ✓ Greater and more effective use of “off-site” data
  ✓ A leap in quality/quantity of global satellite-based sensor data
Ensemble Forecasts

• Uncertainty is present in any forecast method
  – Input data & initial state
  – Model type
  – Model configuration

• By varying the initial state and model parameters, an ensemble of plausible forecasts is produced

• On average, the ensemble forecast is usually the best – but costly in computer resources
Regime-Based Forecasts

- Divide weather conditions into characteristic regimes
- Optimize forecasts for each regime
- Often yields a substantial improvement in accuracy...
- ...but requires more thought and expertise
Ramp Forecasting

- Large ramp events are gaining attention since they can drive grid reliability
- Optimizing forecasts to MAE or RMSE tends to reduce ramp-forecasting skill
- Attempting to maximize ramp-specific skill scores may solve this problem
Reliability Diagram

- Compares forecasted probabilities to observed frequencies
- Forecasts probabilities are grouped into bins
- Example: 180-minute ramp rate probabilities
- Issue: Small sample size
Weather Data

- There is a great need for more weather observations
- Can use mesonets, profilers, offsite towers, Doppler radars, other...
- Custom observing networks may be key in the future
- Imply frequent NWP updates (e.g., Rapid Update Cycle 8x per day)

Rapid Update Cycle NWP forecast of a ramp event caused by a frontal system propagating southward
But Where to Measure?

• Improving forecasts 6 hours ahead may require measurements up to 300 km away: a huge area!
• Don’t forget the vertical dimension: surface measurements alone are generally not sufficient, even for “next hour” forecasts
• Be smart: Some locations, heights, parameters may have far more predictive value than others
  ➢ Corollary: “Masts of opportunity” may have little value
• US DOE-funded research under way to optimize observing systems for short-term forecasts
Observation Targeting Procedure

- Initiate many forecasts over a range of initial states
- Map the sensitivity of forecast errors to the variations in each parameter
- Experimental but promising

\[ x_i^a = x_i^f + K(y_i - H(x_i^f)) \]
\[ K = P_f H^T (HP_f H^T + R)^{-1} \]

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Centralized v. Decentralized Systems

• Centralized systems
  – Owned or contracted by the grid operator
  – Lower total cost for multiple plants
  – Easier to set and enforce standards, maintain consistent quality
  – Potential to aggregate data from different plants and improve forecast quality
  – Can make shared investments, e.g., targeted observational network
  – May not allow enough competition

• Decentralized systems
  – Forecasts supplied individually by wind projects
  – No external funding needed – therefore often the easiest choice
  – Standards can be set, but enforcement may be difficult
  – May lead to greater competition among forecast providers
Integration with Grid Operations

• The forecasts may be fine, but will they be used?
• Forecasts should be customized to the real needs of the grid operators
  – Confidence levels on routine forecasts
  – Focus on critical periods, e.g., times of maximum load or maximum load swing
  – Ramp forecasts
  – Severe weather forecasts
• Dedicated staff should be assigned to monitor forecasts
• Other steps to make integration more effective: training, visualization tools, plant clustering
Summary

- Wind forecasting is becoming ever more important as wind penetration grows.
- Current forecasting technology is far from perfect but nonetheless highly cost effective compared to no forecast at all.
- Improvements lie in better models, better use of models, and more observational data.
- Benefits of aggregation and need for large investments (e.g., observational networks) favor centralization of forecasting operations.
Thank you

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