Wind Forecasting

Wind Integration & Wind Forecasting

Lee Alnes
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WindLogics Background

- Founded 1989 - supercomputing industry background
- Atmospheric modeling and visualization
  - US Army – Future Combat System – multi-year forecasting project
  - FAA – selected for 2004 forecasting pilot project
  - US Air Force Operational Weather Squadrons - 140 seats
  - Israeli Air Force - complete forecast modeling system
  - Harvard University - air quality studies for energy industry
  - City of Cincinnati - 3D terrain-following dispersion modeling
  - DOE - real-time diagnostic wind field monitoring
  - NASA - meteorological data assimilation system

- Years of experience in fine-scale forecasting systems
- History of solving the complex and difficult problems
- With VC funding, applying these advanced modeling and analysis technologies to wind energy since 2002

Wind Assessment – Financial Risk – Wind Forecasting
Integrated Wind Understanding

Taking advantage of all the available data:

1) Use best available “gridded” archives of real weather data from government agencies
   - Actual recorded weather data, fully verified to initialize weather forecast models

2) Unlimited integration of tower data and other on-site measurement points

3) Add the best available high-resolution topography and land cover information

4) Properly apply meteorological models and wind field models integrating data over space and time

5) Analyze long-term variation and the financial impact on your specific situation

6) Use wind forecasting to minimize cost and operating impacts & maximize revenues
Weather-Sensitive Decisions & Operations

Staff of 28:
• Focused on forecasting & weather decision support

Grand Rapids Sciences Center:
• 131 processor modeling cluster
• 12 processor R&D cluster
• 8 processor SGI supercomputer
• 10 Terabyte Dual-RAID storage system
• NOAAport Satellite Receiver System

Saint Paul Operations Center:
• 124 processor production cluster
• 8 processor forecasting ingest cluster
• 12.5 Terabyte Dual-RAID storage system
• NOAAport Satellite Receiver System
Atmospheric Complexity

The atmosphere is so complex… So how does this work?
Gridded 3D Weather Data

Integrates all available data sources, from the surface to the upper atmosphere, into a unified and physically consistent state of all grid cells at a given point in time.

Over 160 weather variables collected from:

- Surface / METAR station data
- Oceanographic buoys
- Ship reports
- Aircraft (over 14,000 ACARS/day)
- NOAA 405 MHz profilers
- Boundary-layer (915 MHz) profilers
- Rawinsondes (balloon soundings)
- Reconnaissance dropwindsonde
- RASS virtual temperatures
- SSM/I precipitable water
- GPS total precipitable water
- GOES precipitable water
- GOES cloud-top pressure
- GOES high-density vis. cloud drift winds
- GOES IR cloud drift winds
- GOES cloud drift winds
- VAD winds from WSR-88D NEXRAD radars
Meteorological Models

• Numerical gridded representation of the laws of physics
  – Conservation relations
    • Mass
    • Energy
    • Momentum
    • Water, etc.
  – Physical processes
    • Radiation
    • Turbulence
    • Soil/ocean interactions, etc.
  – Use lots of fast computers
    • Partial differential equations
    • Gridpoint difference values
    • Step all points through time using very small steps (a few seconds per step)
Nesting Modeling Techniques

Modeling “fills the gaps” in both space & time
Weather Modeling Results

Inner grid from July 4, 2003 extracted at 5 minute resolution (played at 30 min/sec)
Showing wind vectors (90 m AGL) and cloud water/precipitation combined isosurface
Understanding Large Areas
Example showing wind speed in color, wind direction as streamlines.

Data Sources:
- WindLogics Archive
- Local Test Towers
- Hi-Res. Terrain / Land Cover

Process:
- Detailed Windfield Modeling

Result:
- 30 meter grid
- 50 meter hub height
Operating Impacts - Xcel Study

Existing (light) and projected future (dark) wind farms on the Xcel North system
Operating Impacts - Conclusions

- Regulation and load following impacts are very modest.
- The significant cost impacts are in next-day time frame.
- If wind “shows up” without being included in unit commitment:
  - Too many units are committed and efficiency of operation suffers.
  - Non-wind generators suffer - inefficient operation of committed units.

Overall impacts are dominated by costs incurred to accommodate wind generation variability and uncertainty in the day-ahead time frame.

Cost impacts can be reduced with adjustments to operating strategies, improvements in wind forecasting and access to real-time power markets.
Wind Energy Forecast System

About This WindFarm
Please report issues to support@windlogics.com

Current Conditions

| Central Standard Time (GMT-6): December 05 2004 at 18:00 | Windspeed (m/s): 4.629 | Wind Direction (deg): 200 | Temperature (C): 14 | Pressure (mb): 1008.8 | Dew Point (C): 10 |

Custom Forecast Results

Day Ahead Forecast  Hour Ahead Forecast

Current Wind Speed Forecast  Current Power Forecast  Integrated Energy Forecast  Two-week MAE by hour

National Weather Synopsis

IR Satellite & Radar  Hourly Wind Speeds (kts)  Eta Forecast Wind Speeds (kts)  GFS Forecast Wind Speeds (kts)

Regional Weather Synopsis

IR Satellite & Radar  Hourly Wind Speeds (kts)  Eta Forecast Wind Speeds (kts)  GFS Forecast Wind Speeds (kts)
Day Ahead Forecast

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<thead>
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<th>Time (CST)</th>
<th>Power (MW)</th>
<th>Wind Speed (m/s)</th>
<th>Direction (deg)</th>
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## Hour Ahead Forecast

The table below shows the forecasted power and wind speed for each hour of the day on 2004-11-25, in CST time.

<table>
<thead>
<tr>
<th>Time (CST)</th>
<th>Power (MW)</th>
<th>Wind Speed (m/s)</th>
<th>Direction (deg)</th>
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</table>
Wind Speed / Power Forecast
Performance Tracking

WindLogics Mean Absolute Power Error
Hour-Ahead (Run Hour = 0)

% Mean Absolute Error

Time in Minutes

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Forecasting Technology & Results

• Forecasting for a specific wind facility uses:
  – Enhanced “Computational Learning System” methods
  – Ensemble techniques using multiple models
  – Custom modeling, custom domains, micro-scale modeling
  – Adaptive adjustment based on local observations
  – … and reliably getting the wind farm data can be the challenge

• Results you should expect for an individual wind farm:
  – Next day power forecast: 10-14% MAE of rated capacity
  – Next day energy: less than 20% MAE of actual energy delivered
  – Next 2-3 hour power schedule: 5-7% MAE of rated capacity
  – The usual disclaimers... Results are site specific, etc.

• When aggregated on a system-wide basis, errors are substantially reduced
  – Approximately 30-50% depending on geographic dispersion
Forecasting – Who Pays?

- **Who gets the value?**
  - Those using the forecast to reduce costs or maximize revenues
  - They need the best possible information to get the most value

- **Who pays?**
  - It works best if this is the same entity that gets the value
  - This isn’t always possible… but be aware of the implications

- **One interesting note…**
  - The forecast actually benefits the non-wind generators

- **Remember:**
  - You get what you measure
  - Optimize for one variable at a time to get optimal solution
  - Don’t mix operating issues and financial settlement issues
  - The value is in **scheduling** wind into **unit commitment**
Centralized or Individual Forecasting

- Centralized has advantages & disadvantages
  - Aggregation, consistency, clearly identified user/customer
  - Be sure to measure the right things and encourage ongoing improvements… this can be tricky to do
  - Do you want centralized or market-based solutions?

- Very likely, there will be multiple forecasting services on the same system
  - Day-ahead bidding and merchant wind will need their own forecast to meet their own value propositions
  - Optimize for one variable at a time to get optimal solution

- Proprietary data concerns?
Utility-scale Wind Energy Forecasting

• Funded in 2005 by Xcel Renewable Development Fund (RDF)

• Team members:
  – WindLogics
  – EnerNex
  – AREVA
  – Utility Wind Interest Group (UWIG)

• Goal:
  – Define, design, build and demonstrate a complete wind power forecasting system for use by Xcel system operators.
  – A key objective is to optimize the way that wind forecast information is integrated into the control room environment, and to evaluate the impact of the wind forecast on control room operations.
Xcel RDF - Project Components

- User requirements for utility-wide forecasting
- Unit commitment forecast
- Load-following forecast
- R&D on Defensive Operating Strategies
  - Value of additional off-site met towers
  - High wind forecasting and warning system
  - Rapid Update Cycle (RUC) model
- Peer review by UWIG’s “Operating Impact and Integration Study User Group”
Xcel RDF - Control Room Integration

• High-fidelity model of control areas
  – Detailed simulator model, including:
    • All generating units, transmission and control center functionality
    – Sophisticated high-resolution chronological simulation

• Sensitivity analysis: 500, 1000, 2000, 5000 MW

• “Significant changes” simulations & training sets

• Identify the new tools & methodologies for operating power systems using stochastic wind forecasts, forecast confidence intervals, etc.

  First identify cost impacts, then design the services, tools and methods to minimize costs!
Control Room Integration
Wind Forecasting

Time series showing forecast with wind speed and cloud cover

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