Power Forecast

Overarching Goal: Make accurate connection node and regional power forecasts. Include error and uncertainty information.

Current approach:

• Establish accurate wind speed forecast at hub height for each turbine
• Estimate power at individual turbines using wind speed forecast
• Roll-up power for connection nodes and regions
• Provide error bars and MAE
Postprocessing System Overview

- Xcel WRF
- NAM
- GFS
- RUC

DiCast Optimization and Integration

- Observed Power
- Power Estimation
- Observed Winds

Xcel GUI
Generating Accurate Turbine Level Winds

DICast Postprocessing

- Utilize DICast to generate hub height wind speed forecasts based on:
  - XCEL WRF model
  - Additional NWS models: RUC, GFS, NAM
  - Observed Nacelle wind speed values at farm turbines
- Each input model is used to create a separate forecast of Nacelle hub height winds
- The wind forecasts from the individual models are then integrated based on past model performance (90 day look back period)
Forecasting Power at Individual Turbines

Different Categories of Wind Farms

• Farms providing reliable real-time turbine winds, power and met tower data
• Farms providing real-time turbine winds and power
• Farms providing partial real-time data
  • Connection node power data available but no turbine winds or power
• Farms providing no real-time data
  • Turbine locations and turbine types known
Forecasting Power at Individual Turbines (cont.)

Farms providing real-time reliable turbine winds, power and met tower data

- Example: XXXX Wind Farm
- Use historical wind/power data to formulate a wind/power forecast model for each turbine
- DICast tunes wind forecast based on real-time observed wind data
- Estimate power at each turbine using power forecast model
- Roll-up power to estimate total power
Forecasting Power at the Individual Turbines (cont.)

Farms providing partial real-time data

- Example: YYYY Wind Farm (connection node power only)
- DICast creates a default wind forecast for the location. It does not tune to real-time observed data
  - Weaker wind forecast performance
- Apply industrial power curve for farm turbines
  - Assumes we have no historical wind/power data for the particular turbine type at the farm
  - Weaker power forecast performance
- Roll-up power to estimate total power
Mean Absolute Error (MAE)

- Assessed at each connection node/forecast lead time pair
  - Forecasted power is evaluated against observed connection node power
  - 15 minute forecasts out to 3 hours
  - 60 minute forecasts out to 72 hours
- 7 day, 30 day, 365 day MAE
- MAE is normalized by dividing by connection node capacity yielding percentage error
- MAE also assessed for PSCo, NSP and SPS regions
Options in Converting Wind to Power – Turbine Power Estimation

- Estimate power at each turbine using forecasted wind at the turbine
- Roll-up power to estimate farm and connection node power

Advantages:
- Supports detailed analysis at the wind farm
- Uses turbine power and nacelle winds
  - Not impacted by turbine availability issues
- Better handles large wind farms covering wide areas involving varying terrain

Disadvantages:
- Complex
- Does not handle loss between farm and connection node
Options in Converting Wind to Power – Farm Power Estimation

• Estimate power at each farm using average forecast wind speed at the farm
• Statistically model total farm power output using forecasted average wind speed

• Advantages:
  • Smoothes out errors at each individual turbine
  • Simpler approach to implement
  • Targets connection node power directly
  • Supports farms where per-turbine observations are not available

• Disadvantages:
  • Need to account for turbine availability
Deriving Power From Wind

- **Industrial power curve**
  - Established for each turbine type
  - Consists of a table mapping various wind speeds to power output
  - Provided by manufacturer

- **Advantages:**
  - Simple and easy to apply

- **Disadvantages**
  - Tends to be inaccurate for turbines in the field
Generic Power Curve
## Sample Variation in XXX Farm Connection Node Power

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<th>Turbine</th>
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</table>
More Challenging Power Curves
More Challenging Power Curves
Deriving Power From Wind Speeds (cont.)

- Statistical data mining approach
- Collect nacelle wind speed/power data
- Model power using wind speed

Advantages:
- Statistically models power against wind using actual data

Disadvantages
- May be as inaccurate as power curve
Deriving Power Using Historical Wind/Power Data

• Data mining power using previous wind and power data as opposed to simply wind data

• Advantages:
  • Significantly more accurate than modeling power using wind alone
  • Can handle challenging power curve geometries
Wind Energy Data Mining Techniques

- KNN
- Random Forest
- Regression Trees
- Neural Networks
- Support Vector Machines
Future Directions

- **Power Forecast Model**
  - Data mine targeting connection node power using Nacelle winds
    - Compare power forecast performance to that of current strategy
  - Utilize additional observed data when available
    - Met tower data
  - Data mine targeting connection node power using WRF/DICast data
    - Perform at farms where observed winds are not available
  - Explore additional data mining techniques
Future Directions

• Availability
  • Incorporate forecasted availability information
  • Produce two forecasts:
    • Forecast 1 assumes full availability
    • Forecast 2 incorporates availability forecast