WIND PLANT FORECASTING: STATUS AND CHALLENGES

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Overview

- Nature of the Wind Forecasting Problem
- Current Forecasting Technology
- Products
- Performance
- Economic Value of Forecasts
- Path to Higher Forecast Value
- Current Research Activities
The Nature of the Wind Power Forecast Problem

- **HARD**: Wind variations at a site are the result of non-linear interactions among atmospheric processes on multiple space and time scales.

- **HARDER**: Not enough data available to specify the initial conditions (especially at smaller spatial scales).

- **EVEN HARDER**: Available wind power is proportional to the third power of the wind speed which magnifies wind speed forecast errors.

Under some circumstances small changes in wind speed can lead to large changes in wind power production – innocuous meteorological features can be significant!
Wind (and Solar) Forecasting Technology
State-of-the-Art Forecasting Tools

- **Days ahead**
  - A statistical composite of an ensemble of statistically adjusted Numerical Weather Prediction (NWP) forecasts

- **Hours ahead**
  - Time series methods with off-site sensor data
  - Feature detection algorithms
  - Rapid update NWP
  - Ensemble composite of these

- **Minutes Ahead**
  - Time series methods with remotely sensed data?
  - Feature detection algorithms with remotely sensed data?
State-of-the-Art Forecasting Tools: The Limitations

- **Data**
  - Resolution of small scale features
  - Boundary layer above hub height
  - Data sparse areas (e.g. oceans)

- **Numerical Weather Prediction**
  - Update frequency (data & CPU constraints)
  - Effective data assimilation (how to do it)
  - Grid resolution (data & CPU constraints)
  - Modeling of physics (e.g. turbulence)

- **Statistical Models**
  - Training sample size & selection
  - Noise control in advanced methods

- **Power Output Model**
  - Modeling intra-facility variability
  - Reliable outage reporting
  - Anticipating shut-down conditions
Forecast Products
Types of Forecasts:
Deterministic vs. Probabilistic

• Deterministic
  - Typically optimized to minimize a performance metric (e.g. RMSE)
  - Deterministic forecasts are simpler to interpret and use

• Probabilistic
  - More information than deterministic forecasts
  - The information difference is inversely related to forecast skill
    • At high skill, the difference is small
    • At lower skill levels the information difference is large
  - Studies have demonstrated that a trained user makes better application decisions when using a probabilistic forecast

• Hybrid
  – Deterministic time series (but with what performance criterion?)
  – Probabilistic confidence intervals
Types of Forecasts: Time Series vs Event

• **Time Series**
  - Values of a parameter are forecasted for a series of specified time intervals during a forecast period
  - Deterministic, Probabilistic or Hybrid
  - Deterministic time series forecasts are usually designed to yield the most favorable score for a selected forecast performance metric
    - Typically results in “hedging” for uncertain events to avoid large penalties from the evaluation system

• **Event (e.g. Ramps)**
  - Occurrence/non-occurrence of defined events is predicted
  - Deterministic, Probabilistic or Hybrid
  - Events of interest are often outliers (i.e. extreme and infrequent)
Operational Application Example #1: California Independent System Operator (CAISO)
• **Renewable Generation**
  - Wind
    - Capacity: ~3000 MW
    - PIRP: 1447.5 MW
    - Most of capacity concentrated in four wind resource areas
  - Solar (on transmission grid)
    - Capacity: ~ 65 MW
    - PIRP: 9.5 MW

• **PIRP: Participating Intermittent Resource Program**
  - Forecasts only for PIRP participants at present
  - Must meet program requirements
  - Receive economic benefits if resource is “in the program”

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CAISO Forecast Products

- **PIRP**
  - Delivery: 15 mins after each hour
  - 7 hour look-ahead
    - begins 105 mins after delivery
    - focus on “next operating hour”
  - Hourly average MW
  - 20% and 80% “POE” MW

- **Day-Ahead**
  - Delivery: 5 AM each day
  - Forecast each hour of the next calendar day (20 to 44 hours ahead)
  - Hourly average MW
  - 20% and 80% “POE” MW
Operational Application Example #2:
Electric Reliability Council of Texas (ERCOT)
**ERCOT Background Info**

- **System Characteristics (2009)**
  - Average hourly load: 32,101 MW
  - Range: 21,349 to 63,453 MW

- **Wind Generation (Feb 2011)**
  - Wind Capacity: 9431 MW
  - Most of capacity concentrated in a small area of NW Texas
  - Frequent occurrence of large system-wide ramps
  - Curtailments are common due to transmission constraints
    - Actual production rarely above 6500 MW due to curtailments
    - Without curtailment production would frequently exceed 8000 MW

**Distribution of ERCOT wind generation resources**
ERCOT Forecast Products

- **Short Term Wind Power Forecast (STWPF)**
  - Delivery: 15 mins after the hour
  - 0-48 hour forecast
    - first interval begins on the hour
  - Average hourly MW
  - 80% POE MW (labeled as WGRPP)

- **ERCOT Large Ramp Alert System (ELRAS)**
  - Delivery: every 15 minutes
  - 0-6 hr forecast
    - first interval begins at time of delivery
  - POE for ramp rate thresholds for 3 time periods beginning at interval
  - List of ramp events with attributes
  - Situational awareness information
ELRAS
Ramp Rate Forecast

- Top row depicts POE values for upward ramp rates over several thresholds for (left to right) 15, 60 and 180 minute periods beginning every 15 minutes.
- Bottom row show the POEs for downward ramp ramps for the same periods and thresholds.
ELRAS Ramp Event Forecast

- Event defined by a ramp rate threshold over 15, 60 or 180 minutes
- Forecasts of ramp amplitude, duration, max ramp rate and start time for each “event”
- 80% confidence band (red bar) for each parameter
- Description of the processes expected to cause the ramp

Observed Ramp for this Case
- Amplitude: -3676 MW
- Duration: 230 min
- Max Ramp Rate: -515/15 min
- Start time: 1630 CST
Forecast Performance
Evaluation Metrics

• **Deterministic**
  - **Time Series**
    • Most widely used: Bias, MAE & RMSE
    • Skill Score
      - Percentage improvement of a metric relative to a reference forecast
      - Persistence and climatology are typical reference forecasts
    • Ideally, metric should measure a user’s sensitivity to forecast error
  - **Event**
    • Hit rate, Miss rate, False Alarm rate
    • Critical Success Index (CSI): combines these 3 parameters

• **Probabilistic**
  – **Three key attributes**
    • Reliability
    • Sharpness
    • Resolution
  – **Need a measure of all three factors**
    • Brier score, Ranked Probability Score (RPSS), etc.
Factors that Impact Forecast Performance

- Skill of the forecast method
- Magnitude of wind variability
- Scales and types of processes causing the wind variability
- Representativeness and quality of data from the wind plants
- Distribution of wind speeds along the power curve during evaluation
- Amount of diversity (uncorrelated behavior) in the wind power production within wind plants and among wind farms for regional aggregates
- Forecast objective and the forecast evaluation metric
  - objective and evaluation metric may be inconsistent
Forecast Performance Factors: Amount and Quality of Wind Farm Data

A comparison of forecast performance over a 1-year period at two similar-sized, adjacent wind farms with very different onsite data quantity & quality.

Reference Wind farm (Multiple Met Towers)
Annual Forecast MAE: 11.3%

Adjacent Wind Farm (Single Met Tower)
Annual Forecast MAE: 14.6%
Forecast Performance Factors: Distribution of Wind Speeds

- Power forecast errors will vary due to variations in sensitivity to wind speed forecast errors
- **Experiment:** assume 2 m/s wind speed error for every hour of the year for different sites in California
- **Result:** more than a 30% change in power forecast MAE
What is State-of-the-Art Forecast Performance?

Individual Wind Farms - Europe

- MAE vs look-ahead time for multiple forecast methods for several European wind farms

- All forecast methods use the same input from NWP models

- Day-ahead MAE ranges from 10-15% for flat terrain to 15-25% for highly complex terrain

- More variation among methods in complex terrain

- From TradeWind report: “Forecast error of aggregated wind power”
What is State-of-the-Art Forecast Performance?

Individual Wind Farms - North America

There have been 2 prominent published wind forecasting benchmarks in North America: (1) Alberta ESO (2) California ISO

**MAE** vs look-ahead time for 2 small regional aggregates (SW & SC) and a system-wide aggregate (EF) on the Alberta ESO system for one forecaster during the Alberta Wind Forecast Pilot Project from Wind Power Forecasting Pilot Project Part B: The Quantitative Analysis Final Report (ORTECH Power)

**RMSE** for day-ahead (0530 delivery) forecasts by season for one wind farm in California for three commercial wind forecast providers from “Revised Analysis of June 2008 –June2009 Forecast Service Provider RFB Performance” (CAISO)
What is State-of-the-Art Forecast Performance?

Typical MAE Ranges for Individual Wind Farms

Compiled from published performance statistics and AWST’s forecasting experience with wind farms in North America and Europe
What is State-of-the-Art Forecast Performance?

Recent Day-ahead MAEs for System Aggregates

- MAE significantly correlated to installed capacity
- Diversity factors also play an important role
  - Example: ERCOT has a highly concentrated region of production in west Texas and experiences higher MAE values for the level of installed wind capacity

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Day-Ahead Forecast MAE of System-wide Wind Power Production

- CAISO
- PIRP
- Germany
- Spain

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What is State-of-the-Art Forecast Performance?

Deterministic Ramp Event Forecasts

- **Metric:** Frequently is CSI

- **Requires**
  - Event definition
    - Alberta: 20% of capacity change in 1 hour
  - “hit” criteria
    - Alberta: +/- 6 hours
    - Alberta: 80-120% of amplitude

- **Results in Alberta and the BPA region:** a low level of skill by the respective criteria
  - CSI between 0.1 and 0.3

CSI scores for ramp forecasts from the Alberta Wind Forecasting Pilot Project (from ORTECH Final Project Report)
Are Wind Power Forecasts Improving?

- Some European entities have a meaningful history of forecast performance
  - How much improvement is due to system expansion and increase of diversity?

- Most North American entities do not
  - Most NA forecast systems have been operating less than a few years

- Need exists to maintain a benchmark record of wind power forecast performance

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**Performance**

History of RMSE of day-ahead forecasts for the aggregated production in the E.On control area in Germany from the TradeWind project report.
Economic Value of Wind Energy Forecasts
Cost Savings with Forecast Improvements

(Based on data from WWSIS)

Path to Increased Forecast Value
Future Prospects: How can forecast value be increased?

- **Use the Forecasts!**
  - Grid integration studies have indicated that there is considerable value in current state-of-the-art forecasts but they are still under utilized.
  - Integrate forecast information into operational procedures.

- **Make more effective use of forecast information**
  - Use of probabilistic forecasts
    - Substantial amount of information is discarded when ONLY deterministic information is provided.
    - Research studies in other (non-energy) applications have indicated that trained users make better application decisions when using a probabilistic forecast.
  - Better forecast integration with decision-maker’s procedures.
Future Prospects:
How can forecast value be increased?

• Improve forecast performance
  - Days ahead
    • Gradual improvement in global/regional NWP model performance due to additional global data, data assimilation system improvements and refinements to NWP models
    • Further near-term improvement due to more sophisticated correction of NWP's systematic errors and statistical weighting of NWP ensemble members – probably diminishing returns soon
  - Hours ahead
    • Expansion of local data availability – targeted observation systems?
    • Use of customized rapid update NWP
    • Application of feature detection algorithms (especially for ramp events)
    • Greater use of statistical time-lagged relationships in time series models

• Decrease Forecast Difficulty
  • Consider diversity when creating incentives for renewable energy development
  • Locate facilities in areas of lower forecast difficulty
Current Research Activities
Wind Forecasting Improvement Project (WFIP)

- **Objective:** Determine how much 0-6 hr wind power forecasts can be improved through the deployment of a customized sensor network and advanced prediction models

- **Venue:** 2 projects
  - ERCOT-region (7-member team led by AWST)
  - MISO-region (project led by WindLogics)

- **Sponsor:** DOE; NOAA contributes their support

- **2-year Project (October 2010 – October 2012)**
  - 12-month deployment of customized sensor network (NOAA & private vendors)
  - Application of a suite of advanced prediction models (NOAA & private vendors)
  - Extensive analysis of meteorological and economic impact
Customized Rapid Update Cycle NWP

- **Objective:** Exploit multiple local data sources with frequent runs of an NWP data assimilation and forecast system to improve 0 to 6 hr forecasts
- **Venue:** ERCOT
- **Sponsor:** AWST
- **Conducting experiments with data**

**August 17, 2010 case**

- Radar at 2300 CDT
- Radar reflectivity
- Actual and Forecasted Wind Speed at Wind Farm in SE part of the SWE region from 2100 to 2400 CDT 17 Aug 2010

**4-hr NWP 80-m wind forecast for 2300 CDT**

**Research**
WindSENSE

Objective: Develop and test methods for observation targeting (i.e. determine the variables and locations that are the best to measure to get most forecast improvement)

Venue: Tehachapi Pass and Mid Columbia Basin
Sponsor: DOE/Lawrence Livermore National Laboratory
  - Prime Contractor: AWST
Multi Phase 3 year Project
  - Develop Ensemble Sensitivity Analysis (ESA) tool
  - Test ESA in Tehachapi Pass and Mid Columbia Basin
  - Evaluate reliability of ESA results for Mid Columbia Basin

Sensitivity of 3-hr forecasts of 80-m wind speed in white box to changes in vertical temperature difference at forecast production time
WindNET - Hawaii

- **Objective:** Demonstrate short-term (0-3 hr) wind power forecast improvement from deploying sensors at targeted locations
- **Venue:** Big Island of Hawaii
- **Sponsor:** DOE/NREL and HECO
  - Prime Contractor: AWST
- **Multi-phase 2.5-year project (2009–2011)**
  1. Conduct observation targeting study
  2. Deploy sensors at identified locations
  3. Conduct forecasting experiments with and without targeted observations
  4. Evaluate change in forecast performance with and without targeted observations