# Overview of Wind Forecasting Research Efforts at UC Davis

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**Solar & Wind Forecasting: Achieving a 33% Solution**

**CEC, Sacramento**

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# Overview of Wind Forecasting Research Efforts at UC Davis

- Recent
  - Quantifying wind ramps in state-of-the-art windplant in California
- Present
  - Quantifying the beneficial impact of wind forecasts on system operation
- Next
  - Wind ramp event prediction tool
  - Improving short-term forecasts via upstream instrumentation

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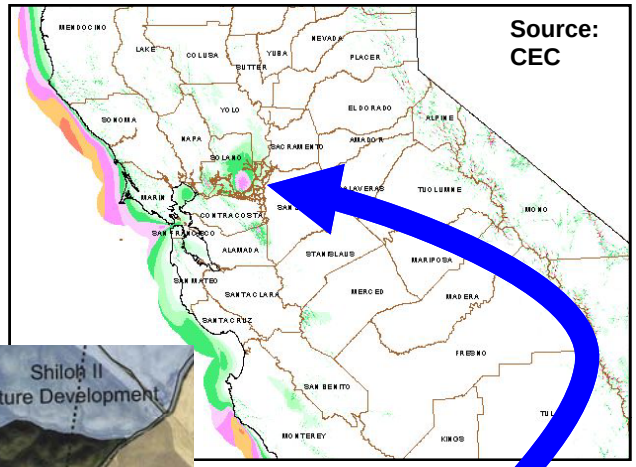
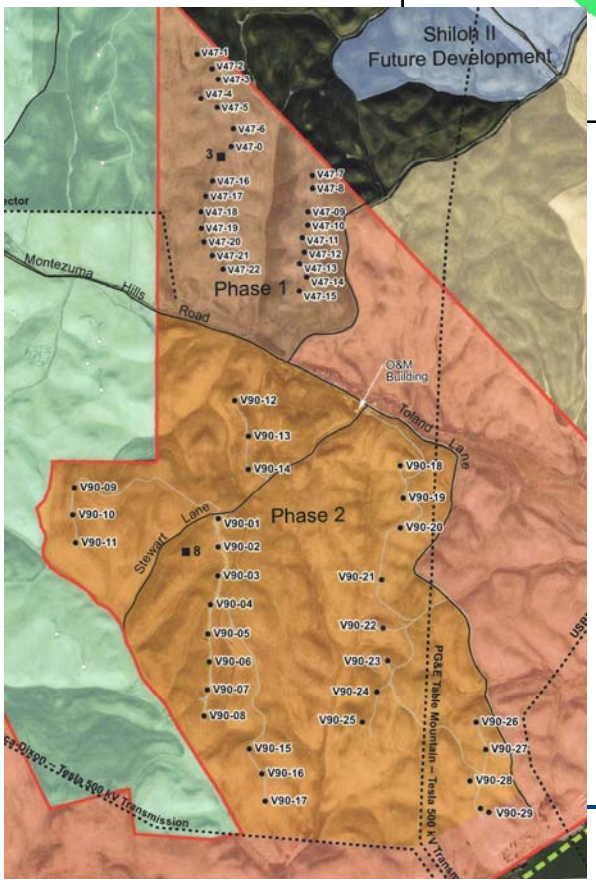
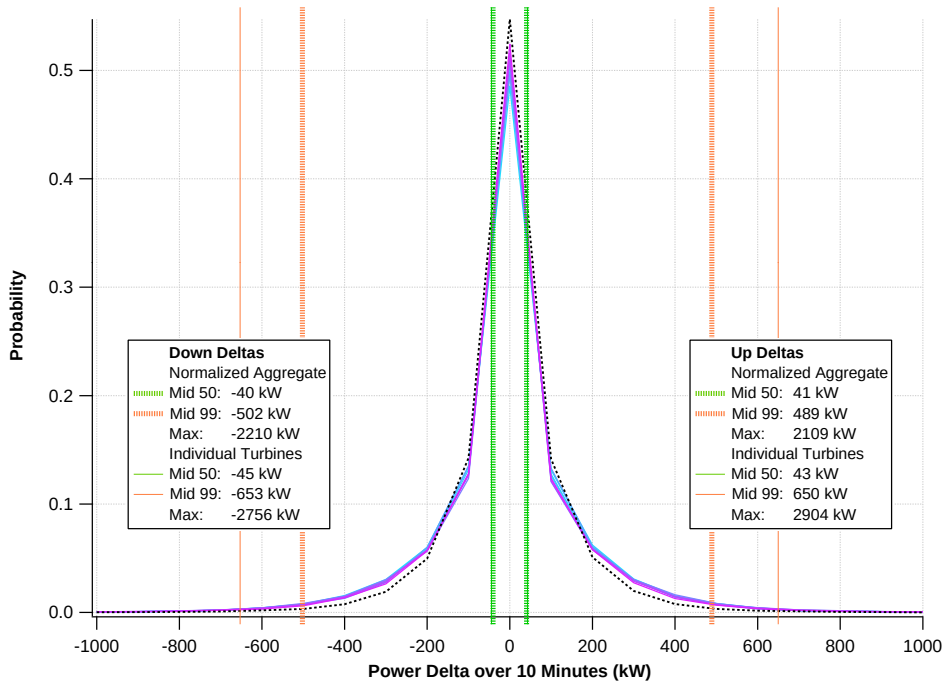
# SMUD Wind Plant Ramp Events

- Excerpted from “Analysis Of SMUD Wind Plants / A Study of Grid Integration and Performance with Existing Datasets” by H. Shiu, UC Davis, 2009
  - Internal report for SMUD
- Solano wind plants
  - 16 / 23 Vestas V47 wind turbines
    - 660 kW each
    - 10.6 / 15.2 MW total
    - 2003 – 2007 (with gaps)
    - 10-minute, hourly data
  - 8 Vestas V90 wind turbines
    - 3.0 MW each
    - 24 MW total
    - 2006 – 2007 (with gaps)
    - 10-minute
    - 21 additional turbines (Phase IIb) installed later
    - Phase III installation currently underway



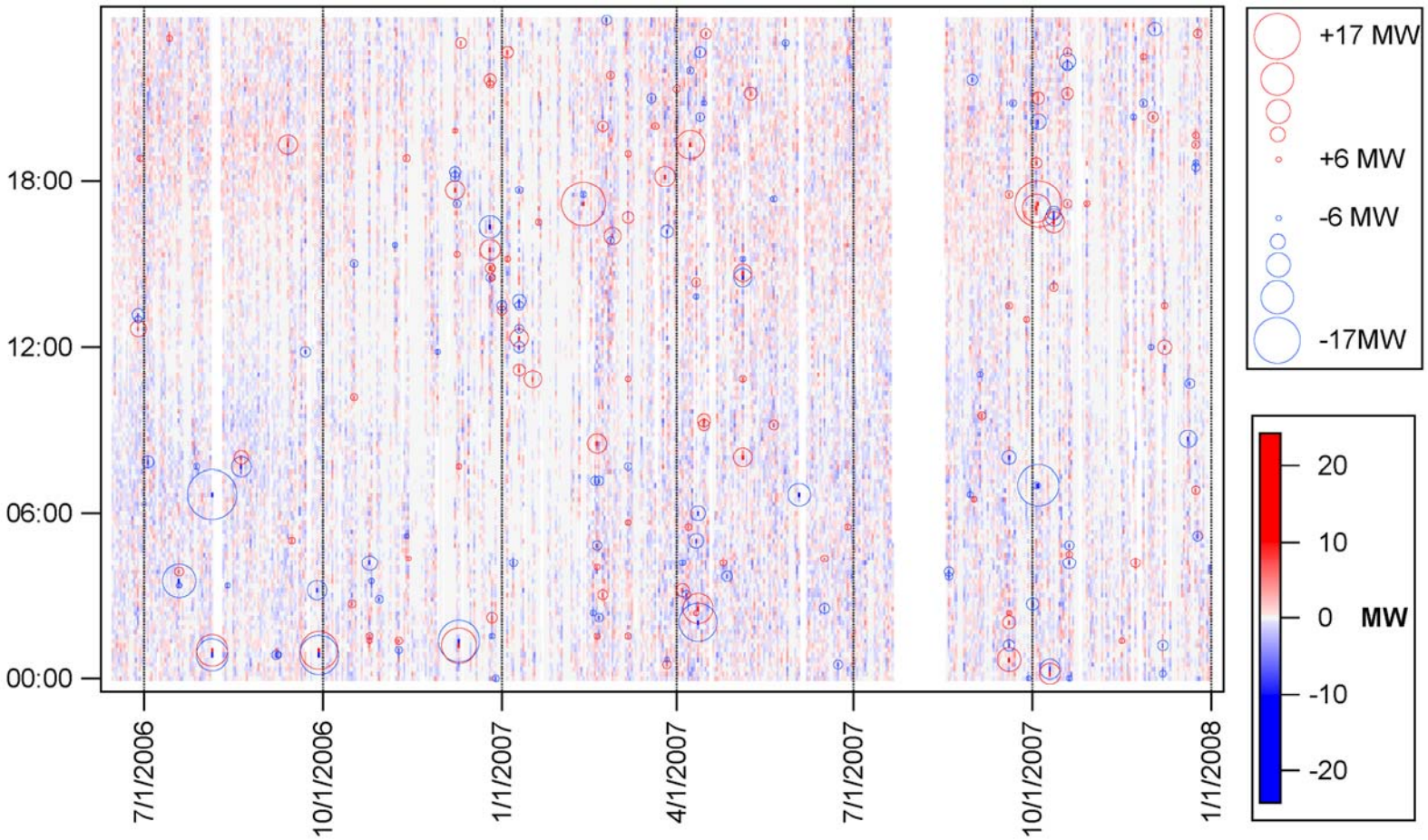
# V90 Power Deltas




10 Minute

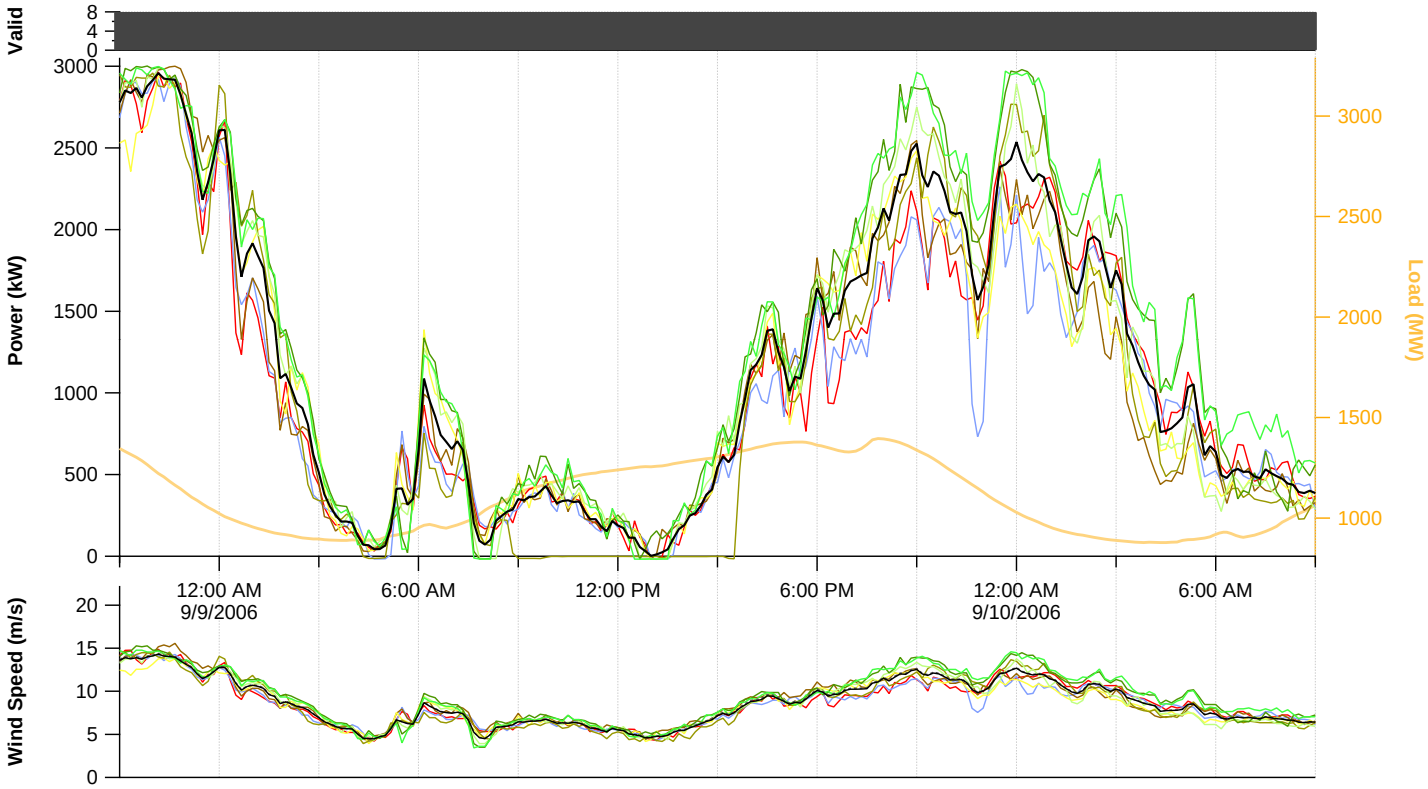
- 8 × 3 MW = 24 MW
- Power changes over 10 minute intervals
  - Faster deltas/ramps could not be studied because of limited data availability
- Plant power deltas normalized to turbine capacity (i.e., 0 - 3 MW)
- 50% of the time, power deltas of the plant were between:
  - -320 kW and 328 kW
  - -1.33% and 1.37% of capacity
- 99% of the time:
  - -4.02 MW and 3.91 MW
  - -16.7% and 16.3% of capacity
- The vast majority of the time, changes are small
  - More turbines further reduce aggregate variability
- However, extreme events, although infrequent, are very important to the system operator.

# Extreme Events, V90, 10-Minute Power Deltas



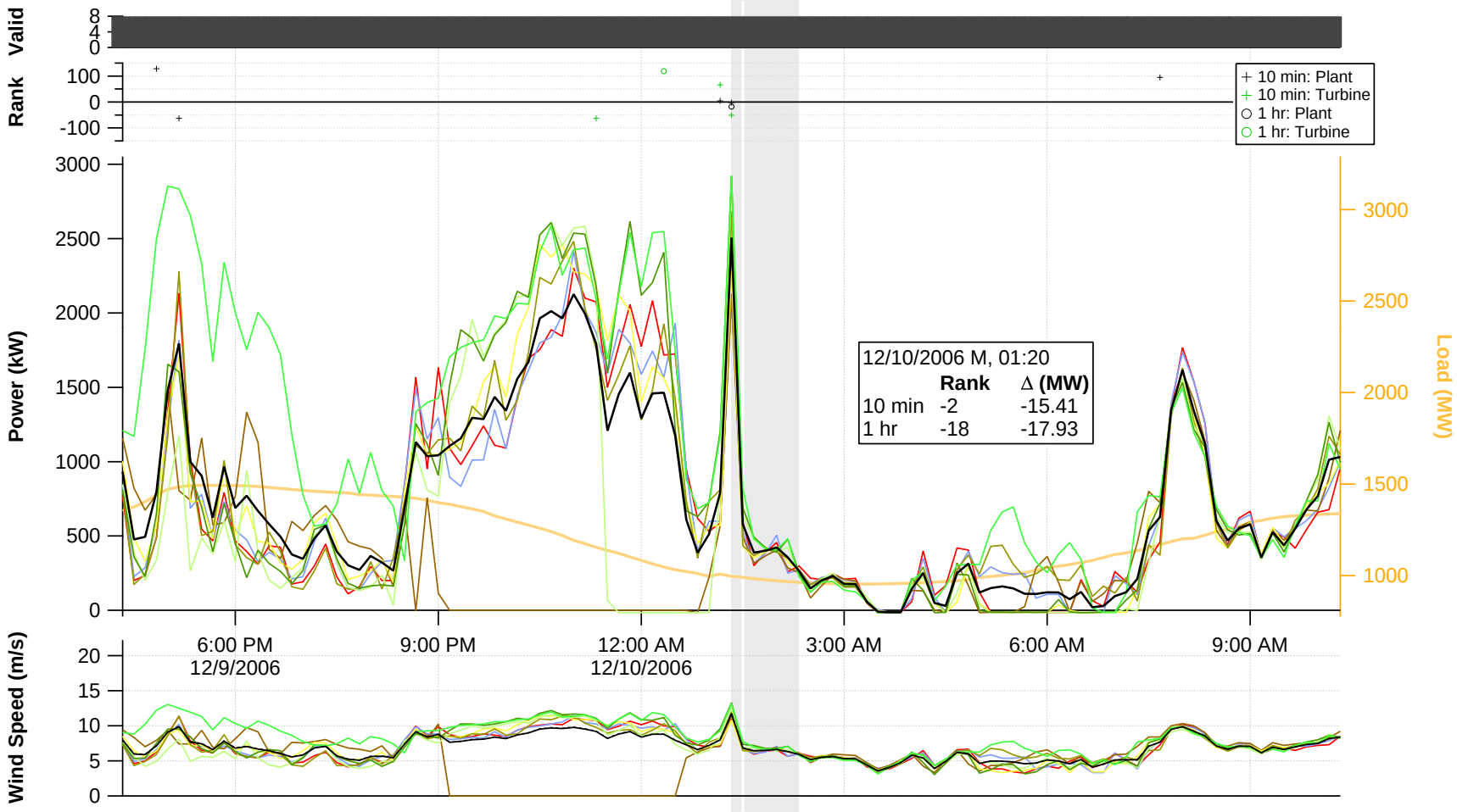

- Top 100 up-deltas and down-deltas marked with circles
- Colorscale exaggerated to visualize more common events
- 5 of top 12 up events and 4 of top 7 down events were anomalous (data error, operator instructed, etc.)

# Typical V90 Power Production



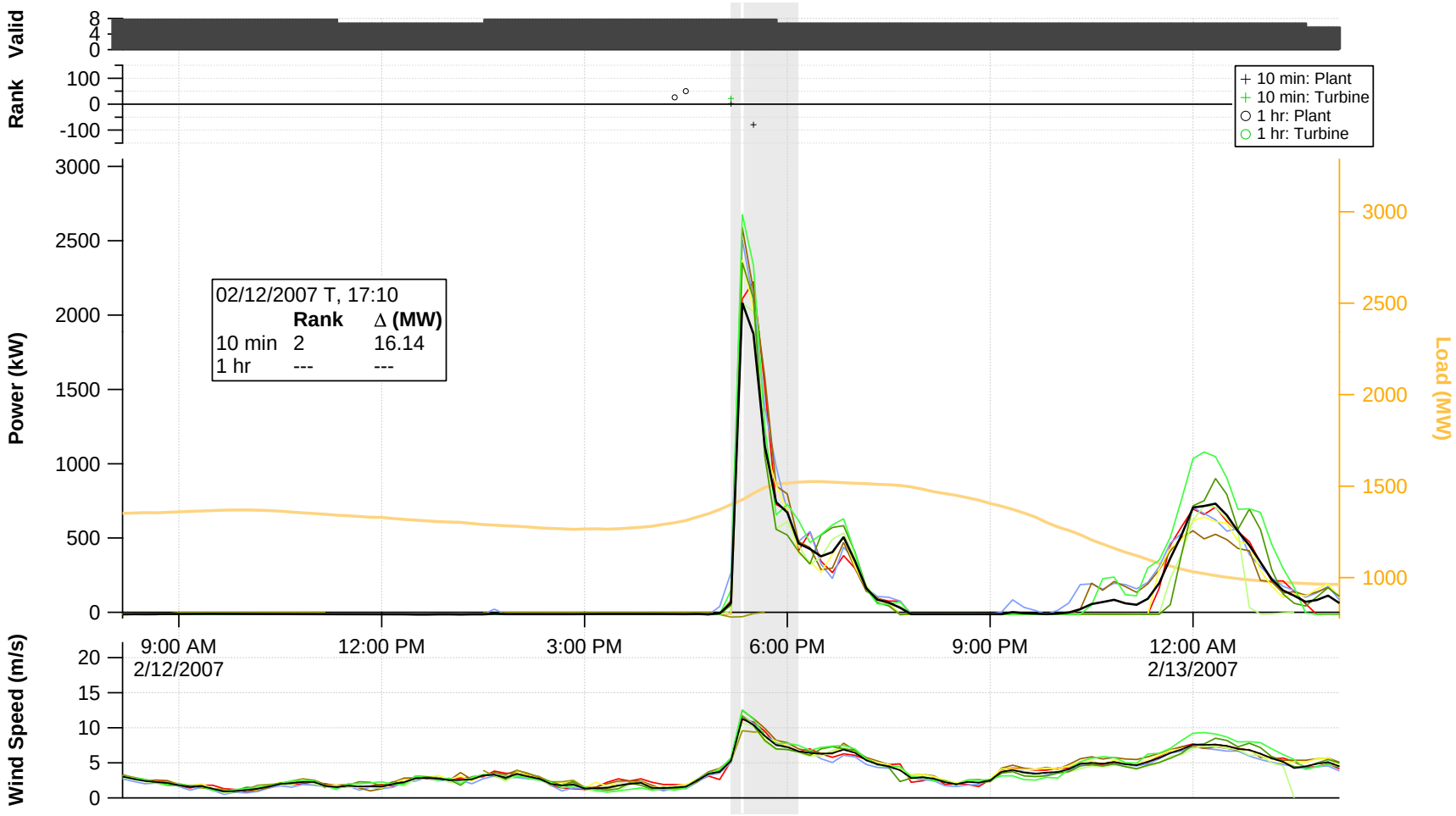

- Typically, the variability of the aggregate is less than that of the individuals

# Extreme V90 10-Minute Down Power Deltas



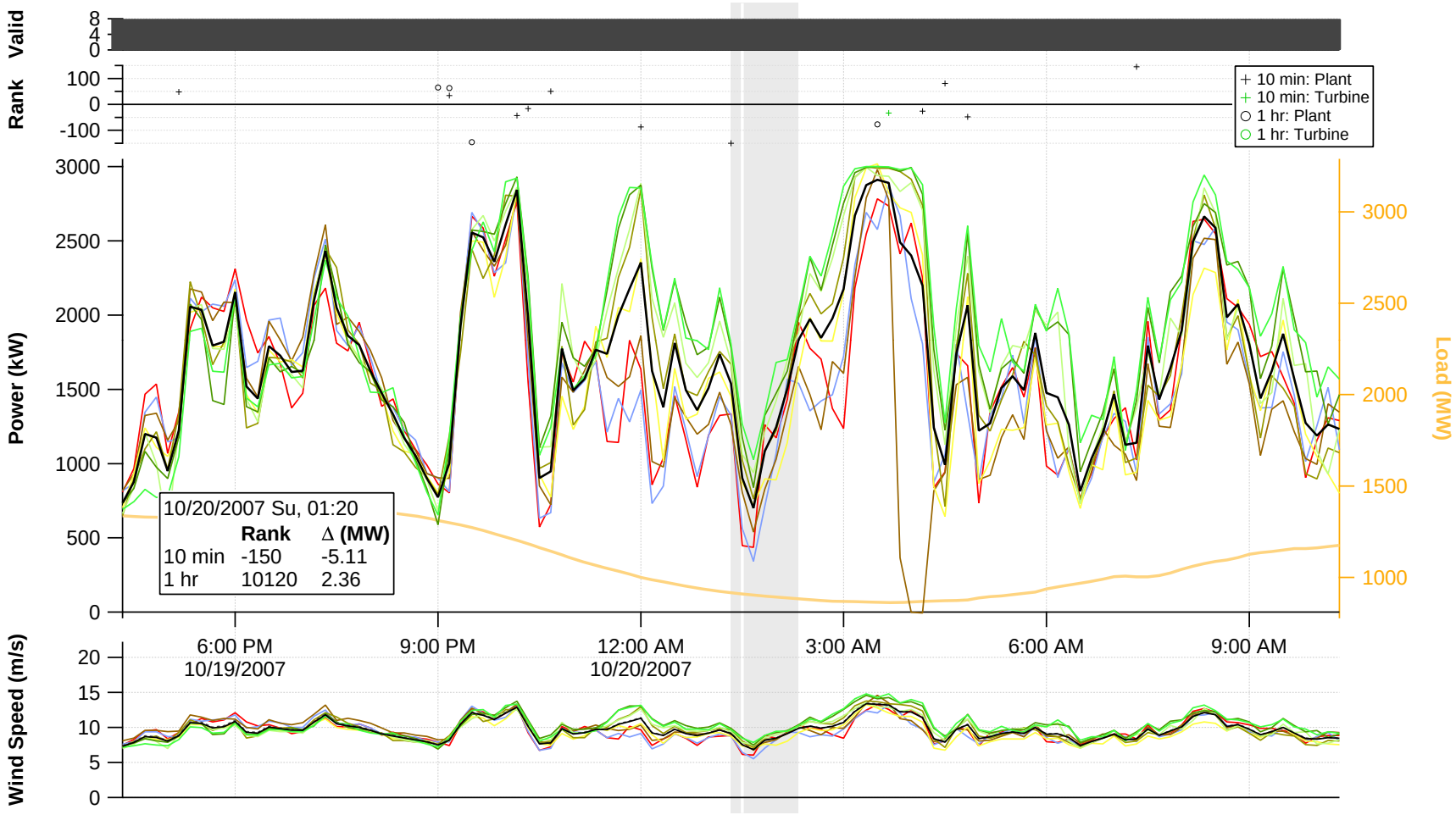

2nd ranked 10-minute down power delta, -15.4 MW (-64.1%)

# Extreme V90 10-Minute Up Power Deltas



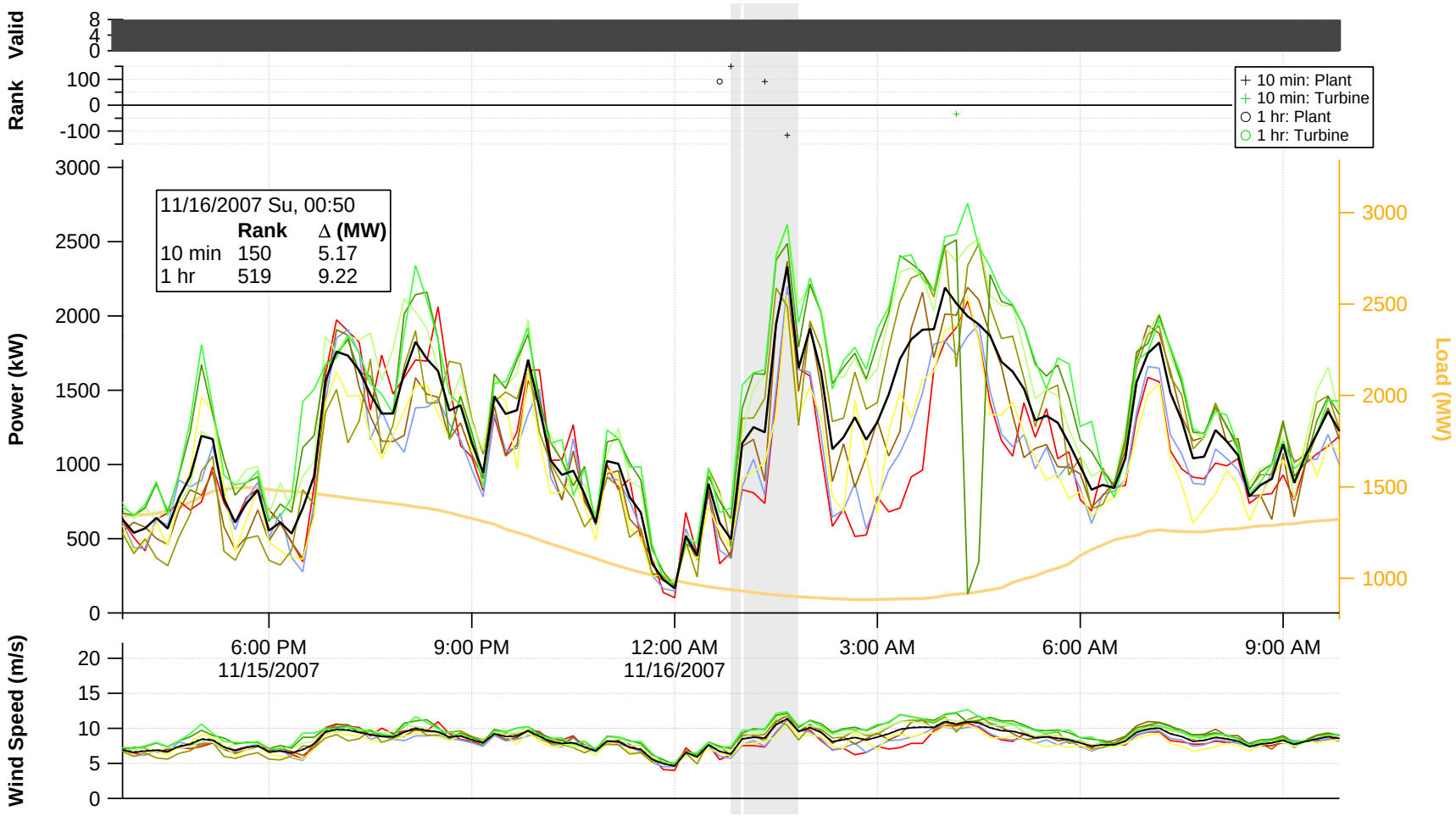

2nd ranked 10-minute up power delta, +16.1 MW (+67.1%)

# V90 Power Deltas



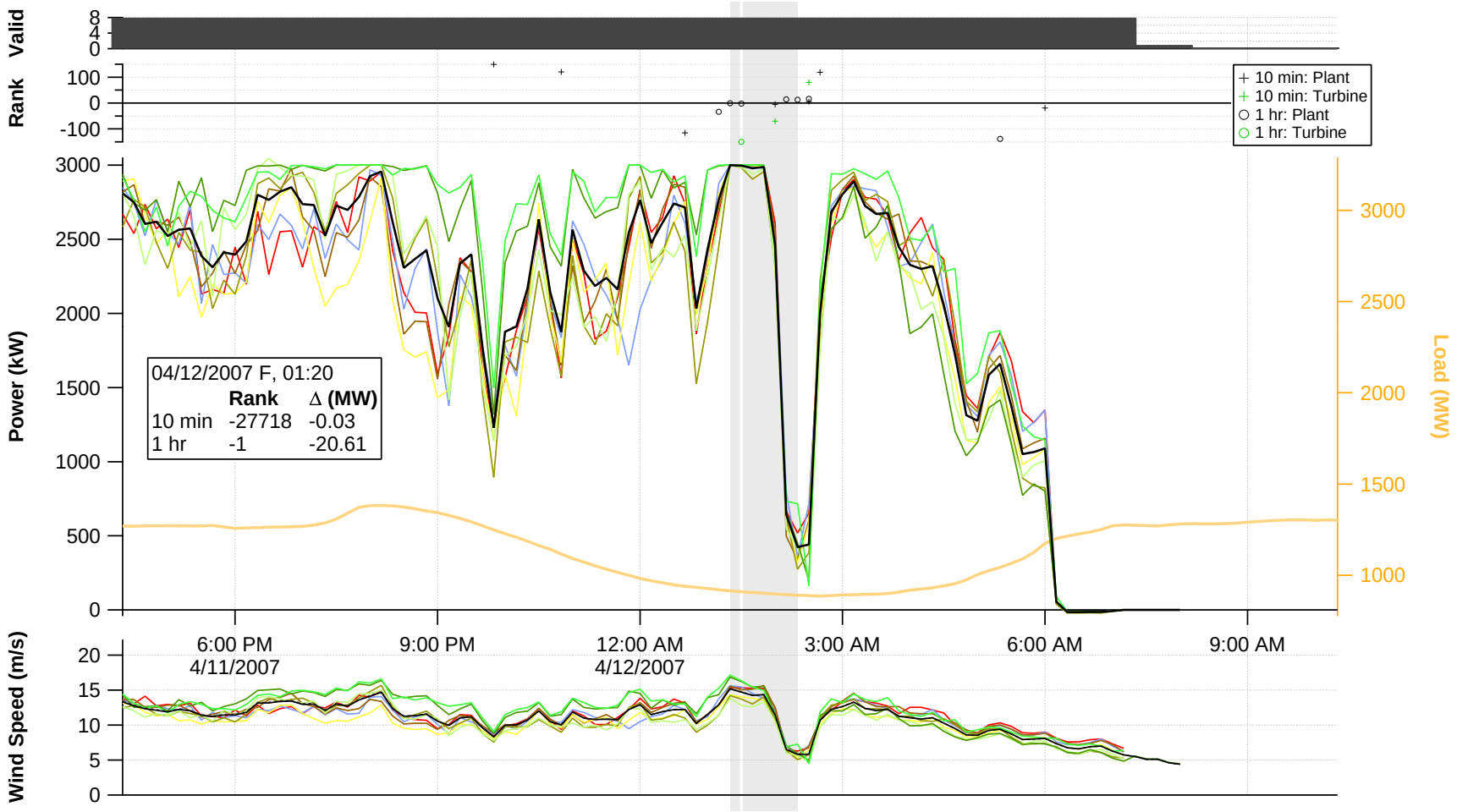

150th ranked 10-minute down power delta, -5.1 MW (-21.3%)

# V90 Power Deltas



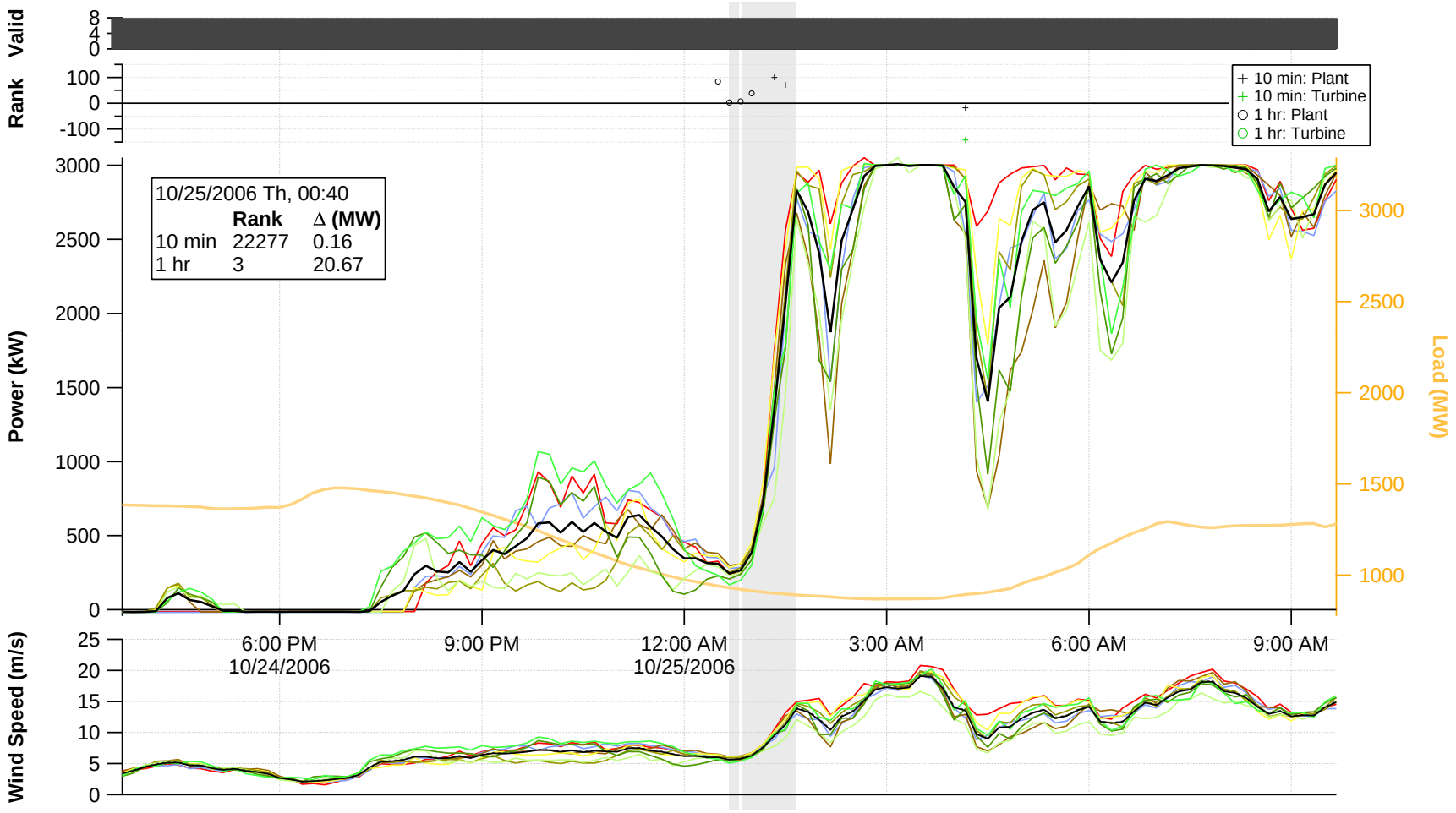

150th ranked 10-minute up power delta, +5.2 MW (+21.7%)

# Extreme V90 Hourly Down Power Deltas




Top ranked 1-hour down power delta, -20.6 MW (-85.8%)

# Extreme V90 Hourly Up Power Deltas




3rd ranked 1-hour up power delta, +20.7 MW (+86.3%)

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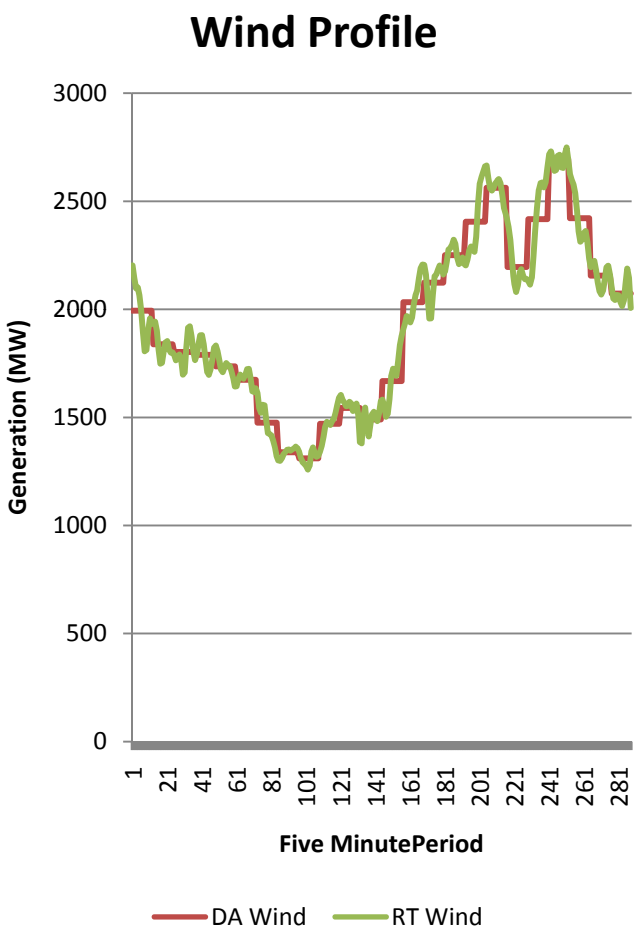
# Measuring Forecast Benefits

- Goal: Isolate the effects of wind forecasts on power systems operations and evaluate benefits forecasts provide

- Model the major power system processes
  - Day ahead, hour ahead, and real time markets
  - Full California system model
  - Wide variety of system conditions
- Model wind forecasts
  - Simulate forecasts similar to current forecasts
  - Adjust simulated forecast parameters individually
- Simulate power system
  - Vary forecast parameters to isolate variables
  - Measure changes to system with different forecasts

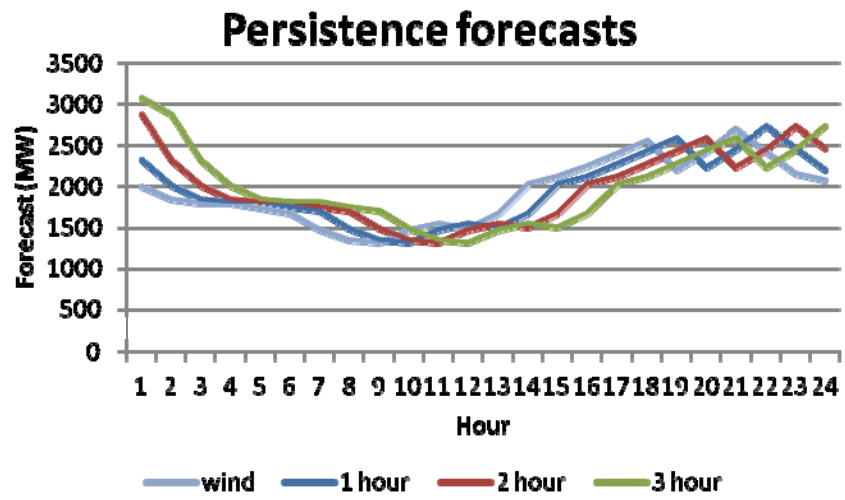
# Simulations

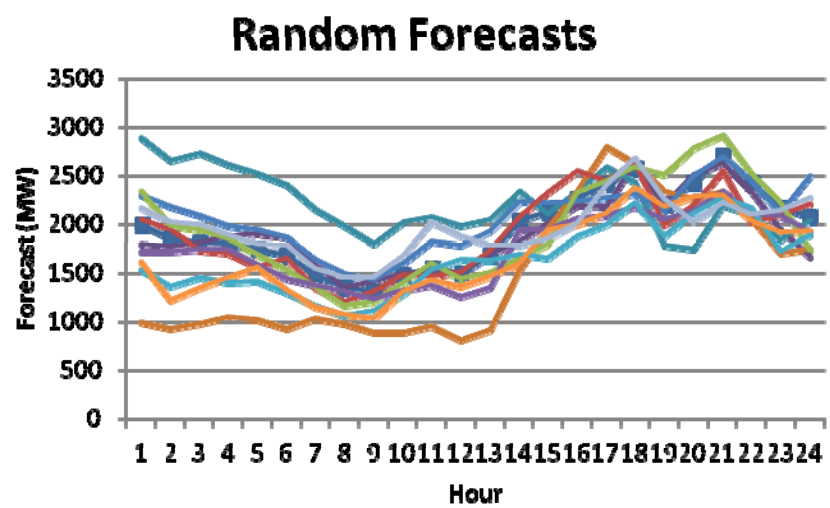
- Full nodal DC network model used for all phases
- Day ahead
  - Full unit commitment process
  - Optimizes a 24 hour window with 1-hour time steps
  - Co-optimizes energy and ancillary services
  - Uses a wind forecast
- Hour ahead
  - Uses unit commitment and schedules from day ahead
  - Optimizes unit commitment 6 hours with 15-minute time steps
  - Uses a wind forecast
- Real time
  - Uses day ahead schedules
  - Locks unit commitment from day ahead and hour ahead
  - Dispatches generation to meet load
  - Optimizes 1 hour windows with 5-minute time steps
  - Uses actual wind profile



# Forecasts Tested

- Bookend
  - Perfect forecast, No forecast, Full output forecast
- Random forecast
  - Forecast statistics simulated
  - Match current levels, and improvements
- Persistence
  - Current generation used as next forecast
  - Reverse persistence, current generation shifted backward



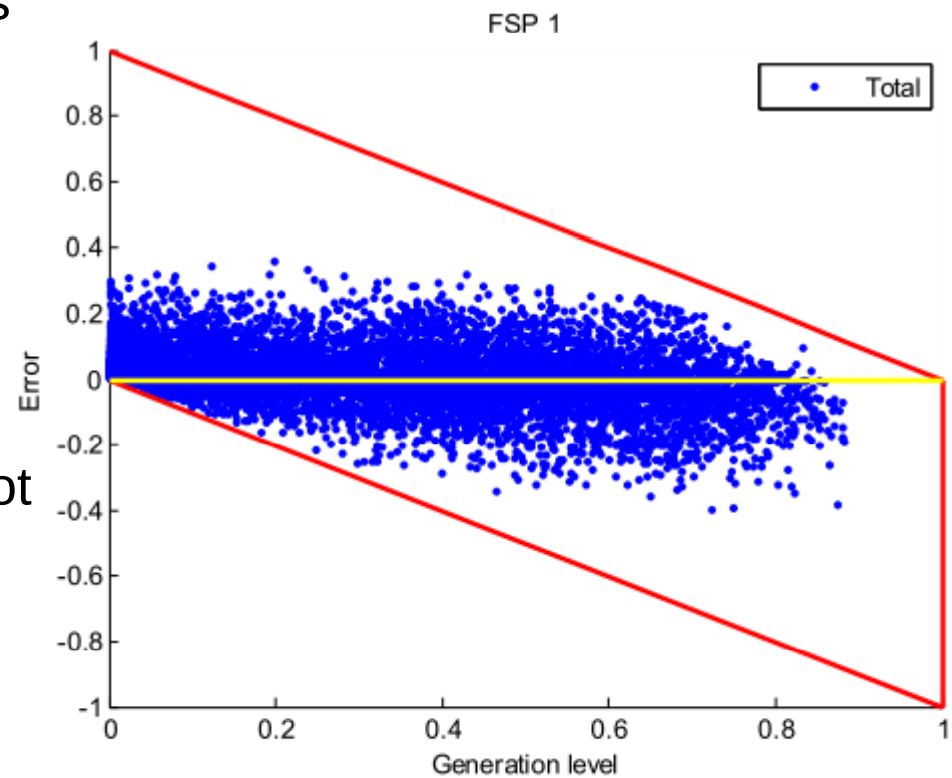
# Evaluating Forecasts

- Forecast error measured as percentage capacity

$$\varepsilon = \frac{Forecast - Actual}{Capacity}$$

  - Each forecast error is limited to ±100%
- Average over time using Mean Absolute Error or Root Mean Square

$$MAE = \frac{\sum|\varepsilon|}{n} \qquad RMS = \sqrt{\frac{\sum \varepsilon^2}{n}}$$

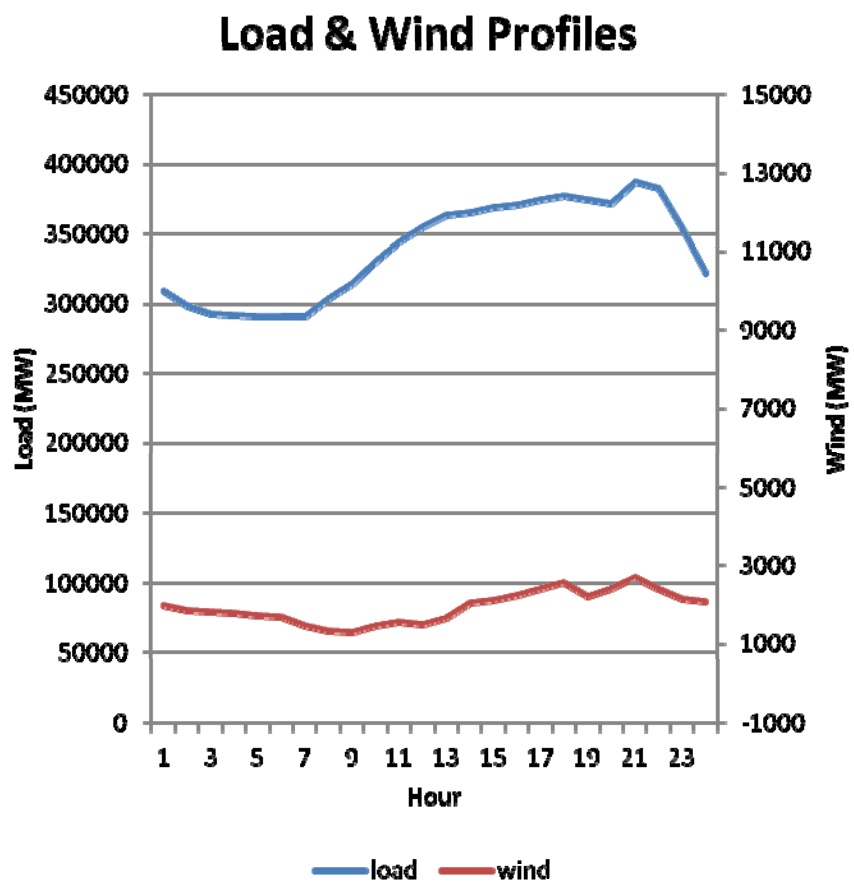


# Scenarios

- Typical day scenarios
  - Representative days from each season
  - Low and high wind days
  - Mid week and weekend days
  - High and low hydro cases
- Special case scenarios
  - Spring - low load, high hydro, high wind
  - Summer – extreme load
  - Winter – storm front
  - Wind maximum diurnal cycle

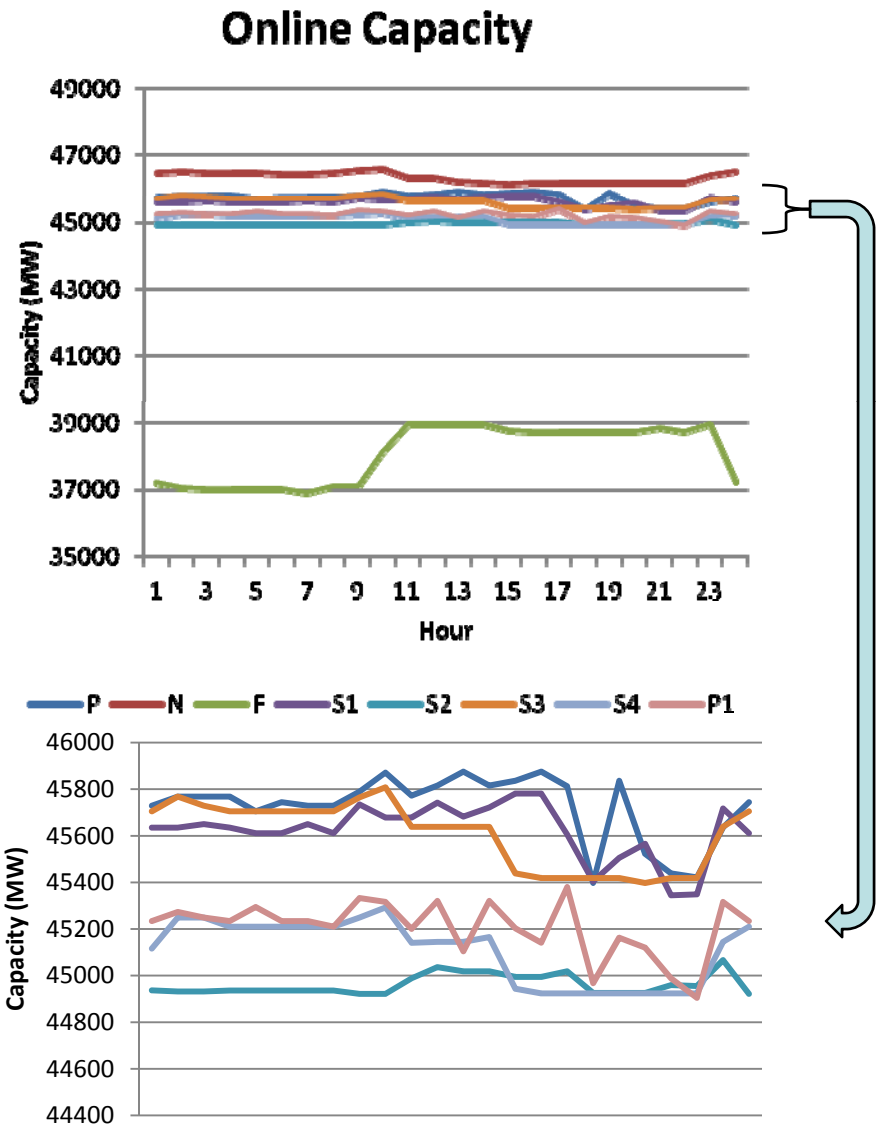
# Early Summer Example

- Summer day
- Peak load 38.7 GW
- Min. load 29 GW
- Wind capacity 7.5 GW
- Peak wind 2.7 GW
- Min. wind 1.3 GW
- Capacity factor 26%



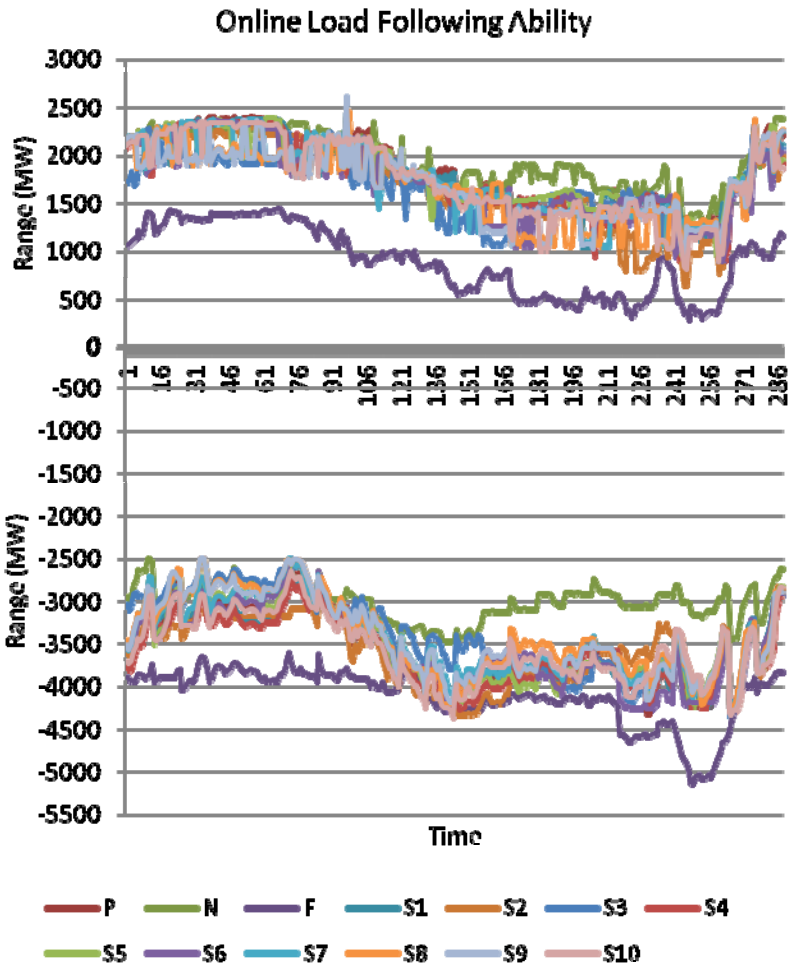
# Unit Commitment

- Forecasts affect online capacity
  - Over forecasting reduces capacity
  - Under forecasting increases capacity
- Online capacity affects costs
  - Over commitment increases minimum load costs
  - Under commitment increases short start costs
- Online capacity affects reliability



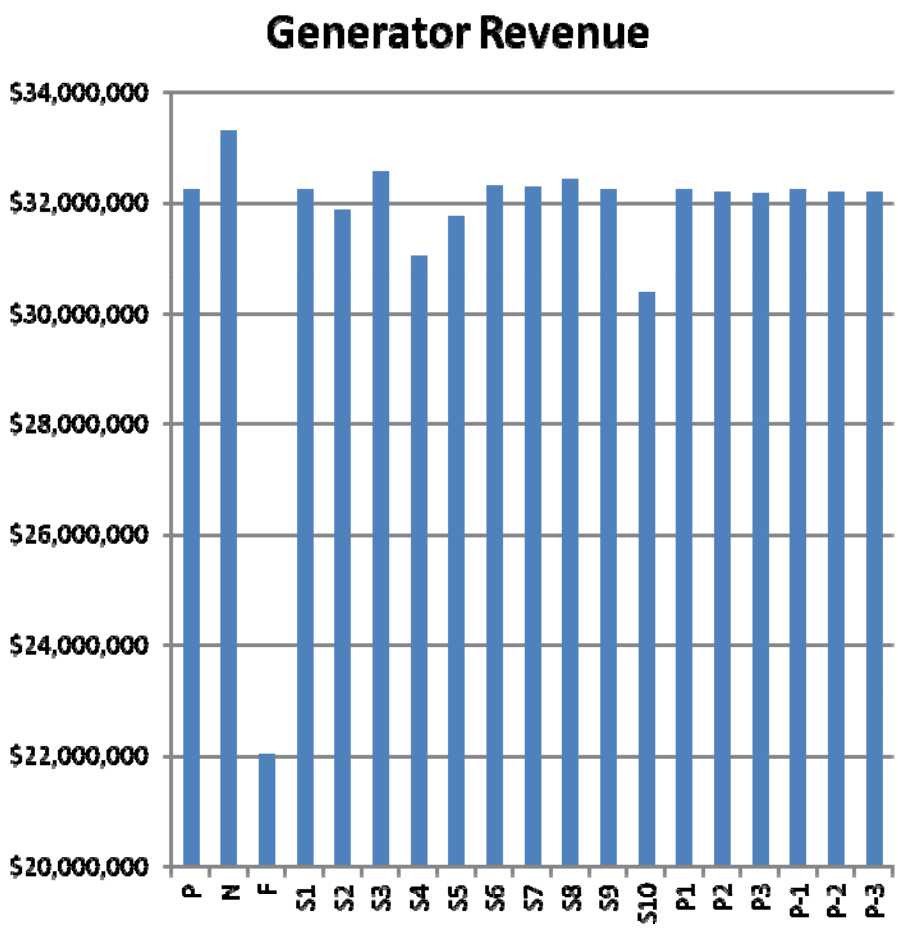
# Load Following

- Measure of maneuverability of online generation
- Unit commitment and dispatch patterns affect flexibility
- Forecasts affect the system's load following ability and needs



# Economics

- Prices and costs can be affected by forecast error
  - Over forecasting decreases forward prices and increases real time prices
  - Under forecasting increases forward prices decreases real time prices
- Congestion and loss costs are affected
- Can lead to large swings in revenue for generators
- Load costs don't necessarily follow same patterns



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# Wind Ramp Event Prediction Tool

- Wind Ramp Event: large change in energy generated in a wind resource area due to rapid changes in wind conditions
  - System operators need warning of wind ramp events to keep system balanced
- Identify wind ramp events in CAISO production data and corresponding atmospheric conditions for all four California wind resource areas
- Develop and calibrate event prediction tool for CAISO
- Evaluate tool effectiveness in real-time
- Partners:
  - CAISO

# Improving Short Term Forecasts via Upwind Instrumentation

- Identify optimal locations and sensor types needed upwind of Tehachapi windplants for short term forecasts
  - Focus on improvement of 0-6 hour forecast
  - Apply DOE funded WindSENSE software to determine optimal sites for upwind instrumentation
  - Determine needed meteorological equipment
    - Lidar, Sodar, Radiometer, Anemometers ?
  - Deploy meteorological equipment at several sites over an one-year period
- Run forecast models with and without upwind data to quantify forecast improvements
- Conduct cost/benefit analysis
- Partners:
  - CAISO, SCE, UCSD, LLNL

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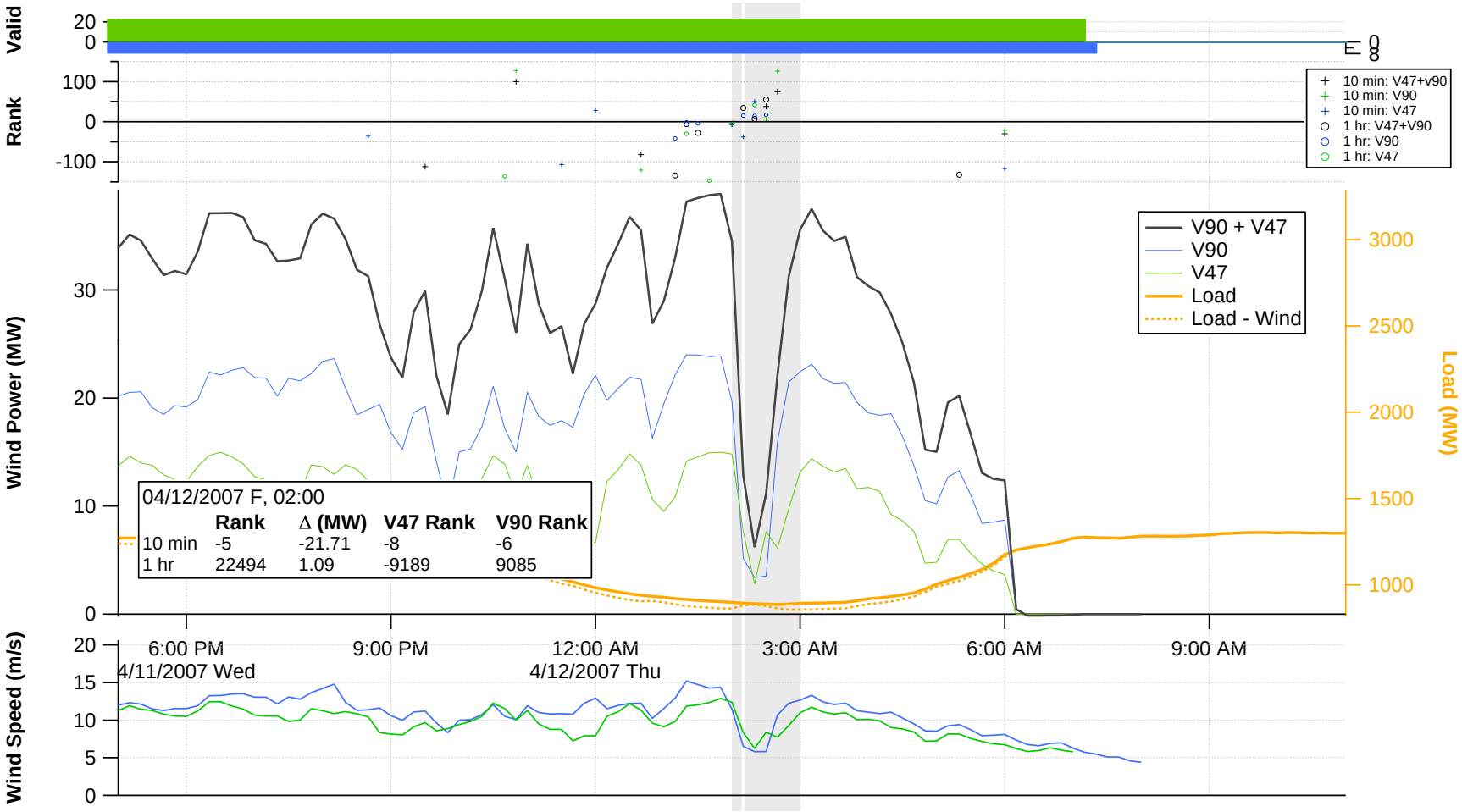
# Combined V47+V90 Plant 10-Minute Power Deltas




5th ranked 10-minute down power delta, -21.71 MW (-55.4%)