Validation of Solar PV Power Forecasting Methods for High Penetration Grid Integration

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SMUD
SACRAMENTO MUNICIPAL UTILITY DISTRICT
The Power To Do More.
TOPICS

• PROJECT BACKGROUND
• TECHNICAL BACKGROUND
• EXPERIMENTAL DESIGN
• PRELIMINARY RESULTS
• ONGOING WORK
• CONCLUSIONS
PROJECT BACKGROUND

• California Public Utilities Commission High Penetration PV Program

• Sacramento Municipal Utility District 100MW Feed-in-Tariff

• Parallel Research Effort (DOE FOA: Improving the Accuracy of Solar Forecasting)
CPUC High Penetration PV Program

• CPUC established CSI RD&D Program in 2007
  – Allocated $50 million for research, development, demonstration and deployment (RD&D) projects to further the overall goals of the CSI Program
  – Adopted the “CSI RD&D Plan”
• CSI RD&D Plan established:
  – Goals and objectives
  – Allocation guidelines for project funding
  – Criteria for solicitation, selection and project funding
• Three Target Areas Established for Program Funding:
  – Grid-Integration: 50-65%
  – Production Technologies: 10-25%
  – Business Development and Deployment: 10-20%
Sacramento Municipal Utility District 100MW Feed-in-Tariff

- SMUD max summer load ~3GW
- Feed in Tariff = 100MW or ~3% of peak load
- ~36 MW of hidden “behind the meter” PV
- SMUD capacity expected to grow, goal of 125 MW net metered PV by 2016
- Power integration issues are very (grid) site dependant: Forecast capability addresses/informs planning, automation and curtailment/mitigation issues
NDFD Grid, Primary & Secondary Sites
SMUD Service Territory

- Primary Sites
- Secondary Sites
- Highways
- Major roads
- NOAA Grid with sites
- Sacramento County

Map produced by NEO Virtus
Data Source: SMUD and CalAtlas
SMUD will be using irradiance network and FiT systems to benchmark forecast performance for 4 forecasters in addition to Neo Virtus beginning in August.

Forecasters will provide hourly forecasts, uncertainty and 5 minute variability on hour ahead up to 5 days in advance for each irradiance sensor and FiT system output.

Sandia Labs will quantify forecast accuracy for various weather conditions and timeframes.

Goal is to understand broadly state of the art in forecast accuracy and ability to trust forecast performance for different timeframes.
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TECHNICAL BACKGROUND

• Irradiance Fundamentals
• PV Power Simulation Fundamentals
• Current Solar Forecasting Methods
• NEO Virtus Day Ahead Forecasting of AC Power
Irradiance Fundamentals

- Direct Normal Irradiance (DNI)
- Diffuse Horizontal Irradiance (DHI)
- Global Horizontal Irradiance (GHI): \[ GHI = DNI \cos \Theta + DHI \]
- 1000W/m² GHI \approx\text{ Full Scale or 1pu (nominal at sea level)}
Irradiance Fundamentals

- Plane of Array Irradiance (POA) = Incident Irradiance on PV array
- POA can be calculated with a knowledge of:
  - Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI) and
  - PV system Azimuth, Tilt, Lat/Lon, Shading Obstruction, Date & Time

Site Specific Solar Resource:
- Latitude/Longitude
- Local weather
- Shading obstructions
- Tilt angle
- Azimuth angle
PV Power Simulation Fundamentals

PV SYSTEM OVERALL EFFICIENCY

- PLANE OF ARRAY IRRADIANCE (W/m^2)
- PV MODULE CONVERSION (IN)EFFICIENCY
- COPPER LOSSES
- INVERTER LOSSES
- TRANSFORMER LOSSES
- PV SYSTEM OUTPUT (Wac)
## Current Solar Forecasting Methods

<table>
<thead>
<tr>
<th>Technology</th>
<th>Time Horizon</th>
<th>Coverage</th>
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<tr>
<td>Satellite</td>
<td>12hr to 7 days</td>
<td>Global</td>
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<tr>
<td>Mesoscale NWP models</td>
<td>12hrs to months</td>
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<td>Aggregated Ground Sensors</td>
<td>1hrs to 3hrs</td>
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<td>SkyImager</td>
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<tr>
<td>Array Scale Sensors</td>
<td>1 to 30 minutes</td>
<td>Array Size</td>
</tr>
</tbody>
</table>
NEO Virtus Method for Day Ahead Forecasting AC Power

- Collect Forecast Cloud-cover (NEO uses NDFD data):
  - Cloud fraction (%)
- Collect PV Array Data:
  - Azimuth, Tilt, Lat/Lon, Shading, Capacity, Inverter, etc.
- Simulate:
  - Sun Position Model: zenith & azimuth angles (°)
  - Irradiance Transmittance Model: DNI & DHI (W/m^2)
  - PV Array Geometry & Shading Model: POA (W/m^2)
  - Photovoltaic Conversion Model: DC Power (Wdc)
  - Inverter & Losses Model: AC Power (Wac)
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EXPERIMENTAL DESIGN

- Build & deploy irradiance monitoring network
- Monitor utility scale PV system power production
- Validate irradiance forecast performance territory-wide
  - 0-3 hour ahead
  - Day ahead
- Validate PV power production forecast for SMUD Feed-In-Tariff (FIT) PV Systems
  - 0-3 hour ahead
  - Day ahead
Primary & Secondary Irradiance Monitoring Station Specifications

• Irradiance Monitoring Network
  – 5 primary monitoring stations
    • GHI, DHI, DNI
    • Ambient temperature
    • 1 minute averages
  – 66 secondary monitoring stations
    • GHI
    • Ambient temperature
    • 1 minute averages
Secondary Station Design & Fabrication

• Irradiance Monitoring Network
  – 5km grid Sacramento
  – NDFD Lambert conformal projection
  – Installed on SMUD utility poles
  – Automated data retrieval via cellular modem
  – 14 month continuous data
Primary & Secondary Monitoring Stations
Day Ahead Irradiance & PV Power Forecast Validation

1-minute, 5km resolution GHI & Temp database

NEO Forecast vs. Measured irradiance validation

NEO Forecast vs. Measured PV power production validation
Solar Forecasting Error Analysis

- Relative (percent) Error*: 
  - RMSE/Capacity 
  - MAE/Capacity 
  - MBE

- Data were filtered for zenith angle >90 (no night time data were used).

- No plant availability information was provided: we assumed 100% availability.

* Hoff, Perez, Kleissl, Renne, Stein: “Reporting of Relative Irradiance Prediction Dispersion Error”
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• Territory-wide measured irradiance data animation
PRELIMINARY RESULTS

• NEO 20-36 Hour (Day Ahead) Forecasting Model PV Production 5/1/12 to 7/2/12
  • $R^2 = 0.9398$
  • RMSE/Capacity = 8.61%
  • MAE/Capacity = 5.57%
  • MBE = -2.39%
NEO’s Day Ahead Forecast vs. Measured
One SMUD FIT PV System 5/1/12 to 7/2/12

SMUD FIT PV Array

R² = 0.9398

Forecast ac production (% capacity)

Measured ac production (% capacity)
NEO’s Day Ahead Forecast vs. Measured PV Production (one system)
Unforeseen Issues, Lessons Learned

• Shadows cast by overhead lines and crossbars causing “artifacts” in daily data
  – Sandia & SMUD are working out algorithm to filter data
• Data logger flash memory failures
  – Code was changed and manufacturer replaced failed units
• Secondary sensors cannot be cleaned economically
  – Precision Spectral Pyrranometers which can be cleaned and maintained are used for system-wide calibration
Overhead Wire Shading Anomalies

Global Horizontal Radiation 6/25/11
SMUD/NEO Virtus Secondary Station #64

Global Horizontal Radiation 07/09/11
SMUD/NEO Virtus Secondary Station #64
Global Network Calibration

• Eppley Precision Spectral Pyranometer (PSP)
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ONGOING WORK

- Development of 0-3 hour ahead forecasts using sensor network
  - Territory-wide GHI
  - Feed in Tariff PV Systems Production
- Filtering of signal noise caused by cross arm and wire shading
- Global calibration of sensor network
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CONCLUSIONS

- Solar forecasting technology is in the earliest stages of development
- Error metrics, time horizons and benchmarks are being developed
- Numerous forecasting technologies are under development
- Performance validation efforts for individual forecasting technologies are being conducted
- There are front runners but currently no clear winners in this technology race
QUESTIONS?

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