Recent Advances in Solar Resource Variability and Forecasting

Dave Renné, Manajit Sengupta, and Ray George
National Renewable Energy Laboratory
Solar Radiation and PV Variability

• **Basic Strategy**
  – Field measurement campaigns
  – Analysis of relationship between irradiance inputs and system power outputs

• **Approach**
  – Surface solar measurements and PV output, 10 second (or faster) data rate, for different climate regimes
  – Third party solar irradiance data from PV central station sites
  – Field campaigns deploying arrays of special irradiance sensors at selected PV central station sites
  – Algorithms relating a single solar station to output of a large PV array
  – Collaborations with PV Variability Working Group, SNL, LBNL, industry groups
Solar Measurements for PV Variability

• **Measurement Needs**

• **Temporal**
  - 1 sec to 5 sec

• **Spatial**
  - 100 m to 500 m to ~5 km
  - Network of 10 to 100 stations

• **Components**
  - Global Horizontal
  - Plane of Array

• **Reference – 1 RSR**
  - Global Horizontal
  - Direct Normal
  - Diffuse
PV Variability – Hawaii Solar Grid

Oahu Solar Array – 100m Central Square, 1.2 km Max Extent

- Central square 100 meters
- Aligned with prevailing wind direction (060°)
- NREL sensors: 1-sec GHI
- Rotating Shadowband Radiometer (square symbol): 3-sec GHI, DNI, diffuse, plus 1-min WS, WD, T
- Nearby NWS ASOS
- Array became operational in March 2010
Analysis of Array Response, Match Ramp Frequency w/Filtered Data
Data from Single Sensor to Est. Ramping for Large PV Station

- Ramps: 1-min Absolute Change in 10 Second Avg. GHI
- Filter: 2-min weighted lowpass – 13 samples at 10 seconds
- This simple filter can match PV ramps for limited data set (few days)

Number of Ramps in 3 Days

Size of Ramp, Watts/M2

- 1 sensor, filtered
- 16 sensors, 1.2 Km
- 11 sensors, 0.65 Km
- 4 sensors, 100 meters
- 1 sensor, no filter

- 4 sensors ~ 0.5 MW
- 11 sensors ~ 30 MW
- 16 sensors ~ 80 MW
New HCEI PV Study - Approach

- Assign separate 1-sec to 1-min data source to each PV area or large PV plant
- Filter high-frequency solar data to match spatial extent of chosen PV systems
- Create average plane-of-array radiation for each plant
- Convert to PV output using PVWatts or similar estimation tool
- Create new downscaling models (e.g. 15-min to 2-sec) based on study requirements
- Pay close attention to correlations between different PV plants – avoid unrealistic results
Many new sources of measured high-frequency solar data in Hawaii make it feasible to conduct grid integration studies using these measurements as input to the models.
Increasing the ramp “lag” (in this case from 10 to 60 sec) always increases the ramp size
Increasing the temporal or spatial averaging always decreases the ramp size
- source: Laura Hinkleman, U of WA
10-sec and 60-sec ramp comparisons
Day 169 (6/17/2010)

- Increasing the ramp “lag” (in this case from 10 to 60 sec) always increases the ramp size
- Increasing the temporal or spatial averaging always decreases the ramp size
- Ramp rate characteristics depend on weather type
  - source: Laura Hinkleman, U of WA
DeSoto Next Generation 25 MW Solar PV Plant

Commissioned October 29th, 2009
DeSoto Next Generation Solar Energy Center

Capacity: 25 Mwac PV
Solar Field: approximately 180 acres
Solar Array: approximately 90,000 panels
17 Containers: 0.8-1.6 MW in size
Backtracking employed
DeSoto Joint NREL/FPL/Sandia Project

DeSoto 25 MW Solar Array – SW Florida – 1.05 km Max Extent

• Obtain high quality solar and PV output measurements from 25 MW plant, and from 17 subarrays within the plant.
• High quality solar measurements from a 1900 acre extended area with potential for several hundred MW
• High quality one-second PV and solar measurements at each PV container site, for use by NREL and SNL to develop more accurate PV models.
• Use data from one, two, or three sensors, smoothed with a Lowpass Filter, to Estimate PV Ramping for any size PV plant, up to 500 MW
• High resolution DC power measurements on one or more PV strings, for validation of the smaller scale (200 meter) fluctuations and PV/Inverter models
• Depending on future funding, there may also be a forecasting activity based on Total Sky Imaging.
Discussion Items

• Need guidance from utilities on the most important time scale for ramp rate evaluation. We currently use the change in (10-second average) PV output over 1 minute.

• For large PV plants, 1-minute ramps are much reduced, however 3-5 minute ramps may still be large (albeit less frequent)

• How important is distributed PV ramping (low density but possibly high penetration) vs. large PV ramping (high density, higher line capacity)
### Current State of Forecasting Across Time Scales

<table>
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<tr>
<th>Forecasting Time Scale</th>
<th>Source of information/ method</th>
<th>Accuracy/Maturity level</th>
<th>Development Path</th>
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| Sub-hourly             | Ground based observations (radiometers/Total Sky Imagers) | (1) Persistence (using radiometers): low accuracy under variable cloud conditions  
(2) Cloud fraction based (using TSI): under development | (1) TSI based cloud advection models  
(2) Statistical models based on high-resolution surface measurements |
| 1 – 6 hours            | (a) Cloud motion vectors (CMV) from satellites  
(b) Numerical Weather Prediction (NWP) Model output [e.g. North American Model (NAM) or Weather Research and Forecasting (WRF) model] | CMV: Available as new product and shows skill  
Potential for improvement/refinement  
NAM, WRF etc: not as accurate as CMV because of  
(1)inadequate initial and boundary condition inputs  
(2)Inadequate cloud physics | (1) Merge satellite-based cloud products with NWP model wind profiles for better cloud advection.  
(2) Build statistical cloud formation and dissipation models by relating to more easily measured parameters (e.g. humidity, temperature etc.) |
| 1-3 days               | Solar forecasts not directly available but can be derived from Numerical Model output [National Digital Forecast Database (NDFD), Rapid Update Cycle (RUC), ECMWF etc.] | Better than persistence, but further work required in  
(1) Availability and assimilation of observations for initialization input  
(2) Improvement in Model Physics | (1) Build capability to assimilate surface radiation into mesoscale model runs.  
(2) Improve cloud formation and dissipation physics |
# IEA/SHC Task 36 Forecasting

<table>
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<tr>
<th>Team &amp; abbreviation</th>
<th>Approach</th>
<th>Numerical Weather prediction model with spatial and temporal resolution</th>
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</table>
| 1) University of Oldenburg, Germany, ECMWF-OL | Statistical post processing in combination with a clear sky model | ECMWF<sup>+</sup>  
- 0.25"x 0.25"  
- 3 hours |
| 2) Bluesky, Austria         | a) Synoptic cloud cover forecast by meteorologists  
 b) BLUE: statistic forecast tool | GFS<sup>+</sup>  
- 1" x 1" and 0.5"x 0.5"  
- 3 hours and 6 hours |
| 3) Meteocontrol, Germany   | MOS (model Output Statistics) by Meteomedia GmbH | ECMWF<sup>+</sup>  
- 0.25"x 0.25"  
- 3 hours |
| 4) Cener, Spain             | Post processing based on learning machine models | Skiron/GFS<sup>+</sup>  
- 0.1"x 0.1"  
- 1 hour |
| 5) Ciemat, Spain            | Bias correction                                | AEMET-HIRLAM<sup>+</sup>  
- 0.2"x 0.2"  
- 1 hour |
| 6) Meteotest, Switzerland, WRF-MT | Direct model output of global horizontal irradiance (GHI) averaging of 10x10 model pixels | WRF/GFS<sup>+</sup>  
- 5 km x 5 km  
- 1 hour |
| 7) University of Jaen, Spain | Direct model output of GHI                   | WRF/GFS<sup>+</sup>  
- 3 km x 3 km  
- 1 hour |

**Global model with post processing**

**Mesoscale models with post processing**

**Mesoscale models**
1-6 hour – Satellite based Cloud Motion Vector Forecast

Perez et al. 2010 patterned after Lorenz et al 2007

Method:
(a) Compute $K_t$ (ratio of GHI and clear sky GHI)
(b) Build motion vector using RMSE statistics from consecutive surrounding pixels

References:
Forecast Validation for all SURFRAD sites

7 – SURFRAD SITE COMPOSITE RMSE -- 2009

SURFRAD Sites:
- Desert Rock
- Boulder
- Bondville
- Penn State
- Fort Peck
- Sioux Falls
- Goodwin Creek

Reference: Perez et al. 2010
Solar Forecast from High Resolution Numerical Models (HRRR)

GHI Feb 15, 2010: Forecast Issued at 05.00 EST
Forecast for: 11:00 EST

Forecast for: 17:00 EST

http://rapidrefresh.noaa.gov/
PV Energy Forecasting Considerations

The NOAA HRRR is a 3-km resolution, hourly updated, cloud-resolving atmospheric model

Hourly results can look pretty good, but sub-hourly variability will be very important
Thank you!

Dave Renné

David.renne@nrel.gov

Ray George

Ray.george@nrel.gov

Manajit Sengupta

Manajit.sengupta@nrel.gov