Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Advanced Cloud Forecasting for Solar Energy's Impact on Grid Modernization

Solar energy production is subject to variability in the solar resource – clouds and aerosols will reduce the available solar irradiance and inhibit power production. The fact that solar irradiance can vary by large amounts at small timescales and in an unpredictable way means that power utilities are reluctant to assign to their solar plants a large portion of future energy demand – the needed power might be unavailable, forcing the utility to make costly adjustments to its daily portfolio. The availability and predictability of solar radiation therefore represent important research topics for increasing the power produced by renewable sources.

To understand better the way that weather affects solar panel performance, we have installed a solar monitoring station at SRS, and are now creating a long-term database of variables associated with solar energy production. These include direct solar irradiance, indirect solar irradiance, solar-generated power and voltage, and infrared irradiance. We have begun an analysis of the relationships between cloud properties and solar irradiance, and how these affect solar power production.

We have also developed and installed an 'analog' solar forecasting system, which forecasts solar irradiance based on the irradiance from previous days for which the weather patterns resemble those of today. The system was seen to work well for test periods when compared to observed data, and is now generating daily forecasts.

Solar monitoring station radiometer installed at the ARC.

Awards and Recognition

Intellectual Property Review

This report has been reviewed by SRNL Legal Counsel for intellectual property considerations and is approved to be publically published in its current form.

SRNL Legal Signature

Signature **Date**

Advanced Cloud Forecasting for Solar Energy's Impact on Grid Modernization

Project Team: M. J. Parker, D. Werth, and R. Nichols

Thrust Area: (e.g., ES, SEM, NS, or NMM)

Project Start Date: October 1, 2016
Project End Date: September 30, 2017

Given that today's electrical grid was not designed to accommodate variable power sources, the growth of solar energy in the Southeast poses a difficult challenge. Energy forecasts in the one to five day range are critical for managing diversified energy portfolios and energy trading floor transactions, and meteorological forecasts play a large role in deciding how much projected electrical demand to allocate to solar panels.

This LDRD focuses on 1) establishing a unique irradiance/cloud and photovoltaic power measurement system at the Applied Research Center and assembling a valuable dataset to characterize the relationships between cloud types and power output, and 2) applying an analog method to improve forecasts in the one-to-five day period. By investing in this project, ATG, with utility partners from the region, will become a leading research group in forecasting solar power production.

FY2017 Objectives

- Create a dataset of solar irradiance, cloud properties, and photovoltaic (PV) power output
    - Establish a solar research station at the Applied Research Center
    - Develop relationships between cloud and aerosol properties, solar irradiance, and solar power output
    - Analyze the timescales of solar variability

- Apply analog modeling techniques to create forecast ensembles and improve one to five day solar forecasts
    - Develop a scheme for the application of analog forecasting to predicting solar energy, and have tested it against existing forecasting tools.
    - Install it to produce daily solar forecasts at SRS

Introduction

Distributed solar energy systems in the Southeastern United States have exceeded thousands of megawatts[1] (MW) and continue to grow[2]. Utilities often assume that roughly 25% of the potential solar resource can be used meet the projected demand, and this conservative estimate is due to the uncertainty in weather forecasts and the consequent uncertainty in projected photovoltaic (PV) power output. If this percentage could be significantly increased through improved confidence in the meteorological forecast, utility grid managers could more confidently allocate more future demand to solar panels and reduce production from conventional sources of energy within their portfolio. According to internal utility estimates, an improvement in forecast accuracy can result in a $20/MWh savings with an additional 80MW available for power production on a 1000MW system.

Clouds and aerosols affect solar energy production not only by reflecting incoming solar radiation back into space, but also by partitioning it into direct normal irradiance and diffuse irradiance, which can alter the solar yield in different ways. The impact of clouds on the solar resource is not well understood, and atmospheric modeling techniques to predict these relationships have not been developed.

The overarching goal of the proposed work is to develop improved methods of forecasting the solar energy resource in the U.S. through an advanced understanding of the impacts of cloud type, and translating this understanding into improved meteorological modeling techniques. This proposal focuses on 1) utilizing a unique irradiance/cloud measurement system in conjunction with measurements of PV power to characterize solar variability and the relationships between irradiance and solar power output, and 2) developing an 'analog' forecasting system to produce forecasts in the 24-48 hour "day ahead" period.

Approach

The plan is to establish a solar monitoring site at the Applied Research Center, which is to include:
1) a solar panel, which records the generated voltage and current, 2) a shadowband radiometer (Fig. 1), to record global, direct and diffuse solar irradiance (Myers, 2005), 3) a sonic anemometer, to record wind speed and direction, and 4) sensors for 2m temperature and relative humidity.

Figure 1. Shadowband radiometer installed at the ARC

We will analyze the data to learn what leads to variability in solar power, including using data to estimate cloud properties, relating these to the partitioning of solar radiation into its direct and

[1] https://www.seia.org/research-resources/top-10-solar-states
[2] https://www.sccommerce.com/news/adger-solar-launching-new-aiken-county-solar-project

diffuse components, determining how the two components affect power output, and determining the timescales on which solar irradiance varies.

We will also develop and evaluate an analog forecasting system () by which a set of weather patterns from the past that resemble that of today (the 'analogs') will be selected, and the observations of solar irradiance subsequent to those analogs are then used to get a forecast of today's solar irradiance.

Results/Discussion

The solar monitoring station at SRS is operational, and we have started looking at the data to explore how changes in solar radiation affect changes in solar power. A power utility must constantly shift the ever-changing demand among its various sources, and this must often be done on short timescales. Clouds induce very short-term changes in solar irradiance (Hinkelman, 2013), and we are therefore interested to learn how likely is it we will see a particular change in solar irradiance in a brief period. For a period from the summer of 2017, we created a probabilistic distribution function (PDF) of change in solar power over a 5 minute period (Fig. 2).

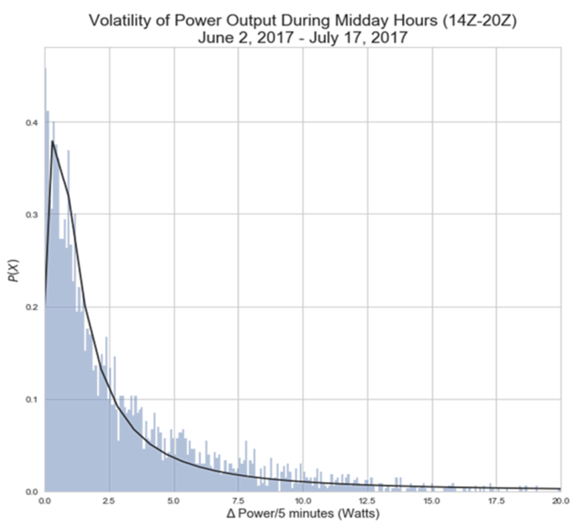

Figure 2 PDF of 5-minute changes in solar power (W).

This analysis included only fair weather cumulus days (no overcast or cloudless days) during mid-day hours (eliminating changes due to sunrise or sunset). Generally, the changes were between 0-7.5 Watts/5 minutes, though one change reached as high as 56.8 Watts.

We have developed an analog system for forecasting solar radiation, similar to that outlined by Hall et al. (2010) and Inman et al. (2013), and tested it at SRS. The system acts by comparing the weather pattern of today (the target) with patterns of the past to find the 5 best matches (the 'analogs'). For example, assume we wish to forecast the next day's solar irradiance at SRS on January 1st, 2007. The surface pressure pattern on that day resembles that of January 9th, 2000 (Fig. 3), so we select the latter as an analog of the former. The solar irradiance subsequent to the analog (that is, on January 10th, 2000) measured at SRS is then considered one possibility of what will occur following the target date (January 2nd, 2007).

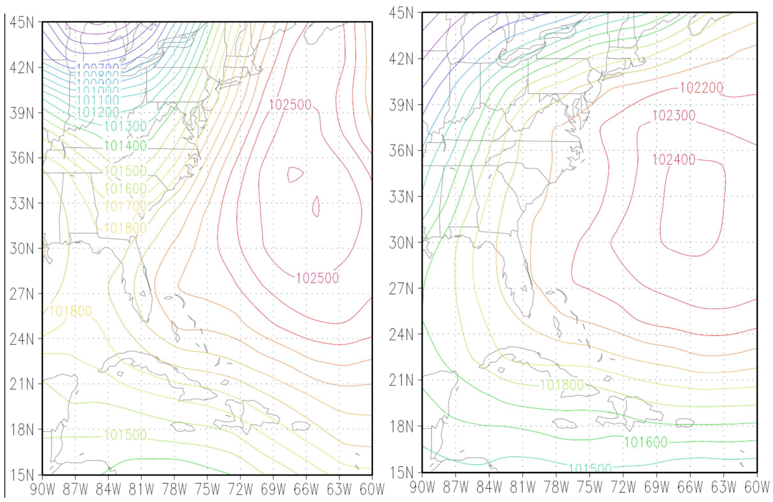

Figure 3 Surface Pressure (Pa) on left) January 1, 2007 (the Target Date), and right) January 9, 2000 (the First Analog)

The time series of solar radiation at SRS for the day following each of the five analog days (Fig. 4) is then used to get the forecast range for the target date. A wide range of forecasts generally indicates greater uncertainty than a narrow range.

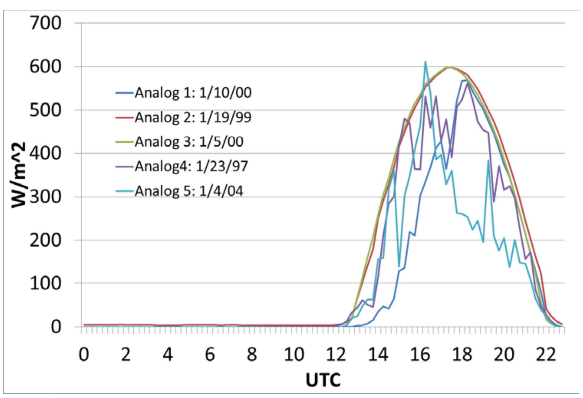

Figure 4 Solar irradiance at SRS corresponding to each analog.

The system was first tested for the month of July, 2017 – each day was forecasted using the analog method, and the forecasts were scored according to how closely they resembled observations. The system was seen to do well when compared to solar forecasts from the North American model (NAM), which ATG currently uses.

The system was then designed to run operationally – producing a new forecast morning for solar irradiance for that day. The forecast for September 25th, 2017 (Fig. 5) does not capture the solar variability perfectly – it is too high early on, and misses the drop at 1600 UTC, but it does indicate that we may expect periods of mostly sunny skies occasionally interrupted by clouds, similar to what was observed.

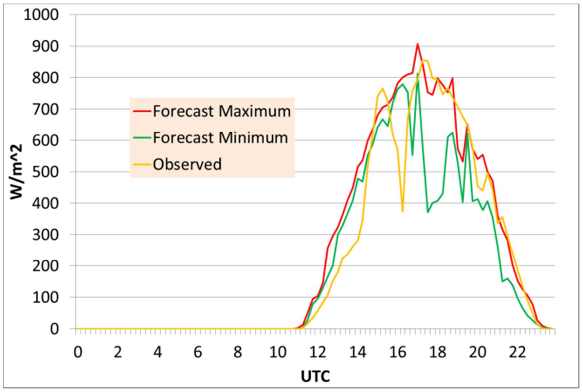

Figure 5 Solar irradiance forecast at SRS for Sept. 25th, 2017, along with the observed irradiance.

FY2017 Accomplishments

• We have developed a solar monitoring station at SRS, and are now creating a long-term database of variables associated with solar energy production
• We have begun an analysis of the relationships between cloud and aerosol properties vs solar power production
• We have developed and installed an analog solar forecasting system
• We are awaiting a funding decision from EERE on a proposal that will leverage these developments

Future Directions

• Run analog forecasting system operationally, and determine its value
• Complete analysis of 1) cloud/power relationship and 2) relationship between timescale and variability
• Collect long-term data from solar site, and make use of aerosol data

FY 2017 Publications/Presentations

1. Submitted for presentation at the 2017 American Geophysical Union Fall meeting in New Orleans (December, 2017).
2. Presented at the 2017 Mini-Tech conference of the Palmetto Chapter of the American Meteorological Society

References

1. Hall, T., R. Thessin, G. Bloy, and C. Mutchler, 2010: Analog sky condition forecasting based on a k-nn algorithm. Wea. Forecasting, 25, 1463-1478, doi:10.1175/2010WAF2222372.1.
2. Hinkelman, L., 2013: Differences between along-wind and cross-wind solar irradiance variability on small spatial scales, Solar Energy, 88, 192-203, doi: http://dx.doi.org/10.1016/j.solener.2012.11.011
3. Inman, R., H. Pedro, and C. Coimbra, 2013: Solar forecasting methods for renewable energy integration. Progress in Energy and Combustion Science, 39, 535-576, doi:10.1016/j.pecs.2013.06.002.
4. Myers, D., 2005: Solar radiation modeling and measurements for renewable energy applications: data and model quality. *Energy*, **30**, 1517-1531, http://dx.doi.org/10.1016/j.energy.2004.04.034

Acronyms

ARC	Applied Research Center
ATG	Atmospheric Technologies Group
NAM	North American Model
PV	Photovoltaic
SRS	Savannah River Site

Intellectual Property

List all invention disclosures, copyright disclosures, patent applications, and patents granted

Total Number of Post-Doctoral Researchers

0