RECENT ADVANCES IN SOLAR VARIABILITY MODELING AND SOLAR FORECASTING AT UC SAN DIEGO

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ABSTRACT

This presentation will provide an overview of recent innovations in the Kleissl Solar Resource and Forecasting Laboratory at the University of California, San Diego. In specific the following results will be covered: (i) A solar variability model that can estimate PV power output ramps based on measurements from a single irradiance sensor and cloud speed from numerical weather prediction model. (ii) A cloud speed sensor to estimate power plant ramp rates. (iii) An advanced sky imaging system and algorithms for intra-hour solar forecasting. (iv) Numerical weather prediction tools to estimate marine layer clouds day-ahead in California.

1. INTRODUCTION

The Solar Resource Assessment and Forecasting Laboratory at the University of California, San Diego is conducting research into modeling tools for solar power integration and forecasting. This paper provides a short summary of the accomplishments and more details will be presented at the conference.

2. SOLAR VARIABILITY MODEL

The wavelet variability model (WVM) for simulating solar photovoltaic (PV) power plant output given a single irradiance sensor as input has been developed and validated previously. Central to the WVM method is a correlation scaling coefficient (A) that calibrates the decay of correlation of the clear sky index as a function of distance and timescale, and which varies by day and geographic location. Previously, a local irradiance sensor network was required to derive A. In this work, we determine A from cloud speeds. Cloud simulator results indicated that the A value is linearly proportional to the cloud speed (CS): A=1/2 CS. Cloud speeds from a numerical weather model (NWM) were then used to create a database of daily A values for North America. For validation, the WVM was run to simulate a 48MW PV plant with both NWM A values and with ground A values found from a sensor network. Both WVM methods closely matched the distribution of ramp rates (RRs) of measured power, and were a strong improvement over linearly scaling up a point sensor. The incremental error in using NWM A values over ground A values was small. The ability to use NWM-derived A values means that the WVM can be used to simulate a PV plant anywhere a single high-frequency irradiance sensor exits. This can greatly assist in module siting, plant sizing, and storage decisions for prospective PV plants.

3. CLOUD SPEED SENSOR

Spatio-temporal variability of solar radiation is the main cause of fluctuating photovoltaic power feed-into the grid. Clouds are the dominant source of such variability and their velocity is a principal input to most short-term forecast and variability models. Two methods are presented to estimate cloud speed using radiometric measurements from eight global horizontal irradiance sensors at the UC San Diego Solar Energy test bed. The first method assigns the wind direction to the direction of the pair of sensors that exhibits the largest cross-correlation in the irradiance timeseries. This method is considered the ground truth. The second method requires only a sensor triplet; cloud speed and the angle of the cloud front are determined from the time delays in two cloud front arrivals at the sensors. Our analysis showed good agreement between both methods and nearby METAR and radiosonde observations. Both methods require high variability in the input radiation as provided only in partly cloudy skies (Bosch et al. 2013).

4. ADVANCED SKY IMAGING SYSTEM AND MINUTES-AHEAD SOLAR FORECASTING

Ground-based visible wavelength imagery is used for short-term forecasting of solar power output. A high quality sky imaging system designed by the authors (the UCSD Sky Imager, USI) is described. The techniques used to detect clouds, determine their height, and to estimate their motion are explained. Application of these methods to generate a power forecast are presented in a case study at the UC San Diego Solar Energy Testbed. A month of data was analyzed, the results are discussed, and ideas for improvement are presented. Finally, recommendations for advancing ground-based visible wavelength imagery and forecast performance are presented.

5. NUMERICAL WEATHER PREDICTION FOR MARINE LAYER FORECASTING IN CALIFORNIA

It is well established that most operational numerical weather prediction (NWP) models consistently over-predict irradiance and their applicability for day-ahead solar forecasting is limited. Overall, error is dependent on the expected meteorological conditions. For regions with dynamic cloud systems, forecast accuracy is low. Specifically, the North American Model (NAM) predicts insufficient cloud cover along the California coast, especially during summer months. Since this region represents significant potential for distributed photovoltaic generation, accurate solar forecasts are critical.

To improve forecast accuracy, a high-resolution, direct-cloud-assimilating NWP based on the Weather and Research Forecasting model (WRF-CLDDA) was developed and implemented at the University of California, San Diego (UCSD). Using satellite imagery, clouds were directly assimilated in the initial conditions. Furthermore, model resolution and parameters were chosen specifically to facilitate the formation and persistence of the low-altitude clouds common to the California coast. Compared to the UCSD pyranometer network, intra-day WRF-CLDDA forecasts were 17.4% less biased than the NAM and relative mean absolute error (rMAE) was 4.1% lower. For day-ahead forecasts, WRF-CLDDA accuracy did not diminish; relative mean bias error was only 1.6% and rMAE 18.2% (5.5% smaller than the NAM). Spatially, the largest improvements occurred for the morning hours along coastal regions when cloud cover is expected. Additionally, the ability of WRF-CLDDA to resolve intra-hour variability was assessed. Though the horizontal (1.3 km) and temporal (5 min.) resolutions were fine, ramp rates for time scales of less than 30 min were not accurately characterized. Thus, it was concluded that the cloud sizes resolved by WRF-CLDDA were approximately five times as large as its horizontal discretization (Mathiesen et al., 2013).

6. REFERENCES

Bosch JL, Y Zheng, J Kleissl, Deriving cloud velocity from an array of solar radiation measurements, Solar Energy, 87: 196-203, 2013, 10.1016/j.solener.2012.10.020.

Lave, M, J Kleissl, Cloud Speed Impact on Solar Variability Scaling - Application to the Wavelet Variability Model, Solar Energy, in press.

Mathiesen, P, C Collier, J Kleissl, A high-resolution, cloud-assimilating numerical weather prediction model for solar irradiance forecasting, Solar Energy, in press.

Urquhart, B, M Ghonima, D Nguyen, B Kurtz, CW Chow, J Kleissl, Sky Imaging Systems for short-term forecasting, in: Solar Resource Assessment and Forecasting, Editor Jan Kleissl, Elsevier, 2013.