Day Ahead Irradiance Forecast Variability Characterization Using Satellite Data

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***Abstract* — This article calculates day head forecast variability as function of historical clearness index based intraday irradiance variability. In this paper we address the use of satellite data as a proxy for the ground data to determine the clearness index of a day, and hourly clearness index variability, here after called nominal variability. The satellite data based clearness index variability is compared to that of ground data based variability to validate the argument that the satellite data could be used as replacement for ground data for this application. A mathematical relationship has been developed to predict nominal variability as a function of the day's clearness index. The article also demonstrates the application of the intraday variability to predict day ahead hourly forecast variability range as a function of the predicted day's clearness index.**

***Index Terms* — Satellite data, solar forecast, solar resource, intraday variability, forecast variability, modeling.**

I. Introduction

Solar irradiance variability is determined by both deterministic and stochastic signals. The deterministic signals have both seasonal and diurnal variation and can be determined using simple astronomical relationships. However, atmospheric conditions, such as water vapor, turbidity, and clouds are the most influential on the solar energy reaching the ground and they are variable in nature. Clouds are the most important variable of the three, yet are the most difficult to predict with the highest certainty.

Numerical Weather Prediction (NWP) and statistical models are used to predict day ahead and longer period energy outputs from variable generation driven by solar and wind energy. The forecasting of solar energy production faces issues similar to those for wind. However, solar forecasting has significant predictability because the sun's path through the sky is known. Nonetheless, solar resource forecasting is not as mature as t wind forecasting.

The overall shape of solar energy production can typically be easily predicted for most of the time if the weather is clear from cloud cover, but significant errors in the level and timing of solar energy production are introduced by the passing of small scale clouds that cause ramps (sudden increases or decreases) in energy production. It has been difficult for most NWP models to predict intraday variability caused by small scale clouds, specially over a single site. However, solar energy forecasting variability can be reduced by aggregating forecast over geographical regions. In this paper we are addressing one way of predicting variability in an NWP-based solar energy forecast for a particular site on a day ahead basis.

The basis for this paper is the concept introduced by Lauret et al. 2015 [1]. The authors have characterized intraday irradiance variability as a function of nominal variability. They have investigated the relationship between nominal variability and daily clearness index and have derived an elegant polynomial relationship. For their investigation of intraday irradiance variability, the authors used data from SURFRAD stations. SURFRAD stands for Surface Radiation Budget Network operated and maintained by NOAA (National Oceanic and Atmospheric Administration). However, there are only limited SURFRAD stations available across the country and it is difficult to use any model developed at these locations for other sites where there is no long term ground data. The authors of this paper are extending this work by using the satellite data at the locations where the SURFRAD data has been used to replicate the results. Such work will make it easy to study intraday irradiance variability at locations where there is no long term ground data. The advantage of the satellite based data is that it is available everywhere within the satellite field of view coverage. The following equations show how the clearness index is computed on an hourly basis (equation 1) and on a daily basis (equation 2). The nominal variability is calculated as the absolute values of finite differences of hourly clearness indices.

$$Kt_j \ = \frac{GHI_j}{GHI\_clear_j} \tag{1}$$

$$KT^* = \frac{\sum_{i=1}^{n} GHI_i}{\sum_{i=1}^{n} GHI\_clear_i} \tag{2}$$

KT* is an average clearness index of a day (daily clearness index) and Ktj is hourly clearness index from which nominal variability is calculated. Further details on the use of Kt for site specific irradiance parametrization can be found in Perez et. al 2011 [2].

Because forecasts are not perfect, excess dispatchable generation capacity must be procured to ensure reliability in the operation of the grid. For grid balancing and other tasks related to variable energy sources, an understanding of the variability associated with the forecast is important for planning for unit commitment and scheduling purposes. In this study we are also attempting to use the site intraday variability to enhance our estimates of day ahead forecast variability.

The remainder of the paper is organized as follows: In Section II we start with a description of the data and methodologies used in the nominal variability calculation. We then show results from the intraday variability of irradiance using the SURFRAD and SolarAnywhere data. In section III we also evaluate forecast upper and lower variability bounds as calculated using the polynomial relationship built from the daily Kt (KT*). In section IV we discuss results and present summaries.

II. DATA and METHODOLOGY

Data has been obtained from several SURFRAD stations from 1998 to 2015. SolarAnywhere® data is obtained for the same locations for the same period as that of SURFRAD stations. Clear sky data has also been generated for the SURFRAD stations. For this work we used data for Desert Rock, NV to demonstrate the algorithm and its application to a day ahead forecast variability evaluation. The forecast model used in this study is derived from the European Center for Medium Range Weather (ECMWF) model.

Lauret et al. 2015 [1] has shown that the nominal variability can be determined from the day's clearness index. We used a similar methodology for calculations of nominal variability and then fitted a polynomial model to establish a relationship between the nominal variability and the daily clearness index. In this paper we are also investigating the use of SolarAnywhere® data in-lieu of ground measurement data to calculate the nominal variability (substituting SolarAnywhere data instead of ground data in the equations 1 and 2) to augment the use of ground data for such applications whenever there is no historical quality ground data at a site. We are also investigating the use of daily clearness index of a site to determine applicable day ahead solar energy forecast variability at a site.

III. RESULTS PREVIEW

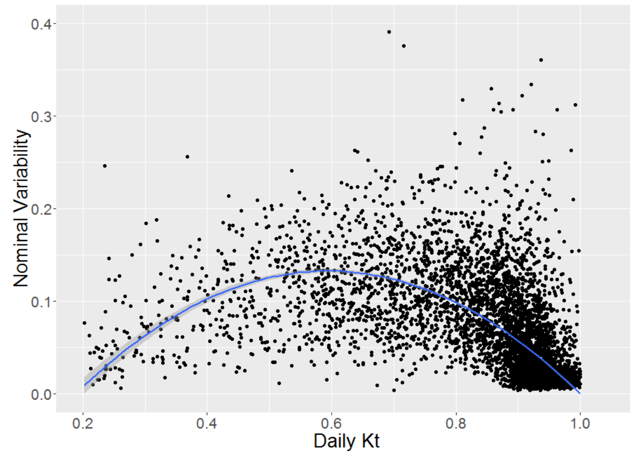

Figure 1: Nominal variability vs Daily Kt using ground at Desert Rock, NV

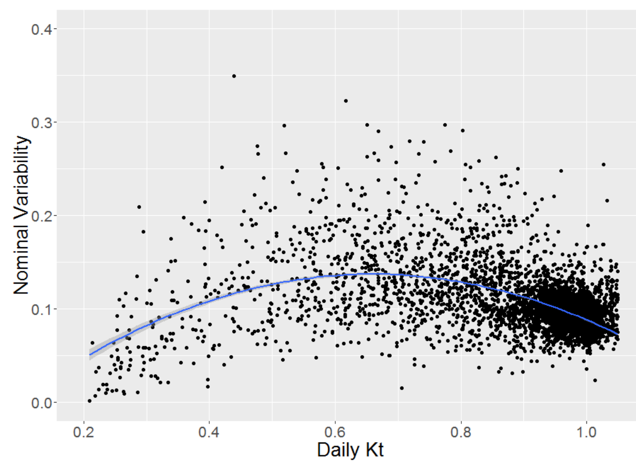

Figure 2: Nominal variability vs Daily Kt using Satellite data at Desert Rock, NV

Figures 1 and 2 show the similarity of intraday variability as calculated using ground and satellite data. Points are more scattered in the case of the ground based variability and smoother from satellite data due to the fact that the satellite misses sub-satellite resolution temporal variability. However, the satellite data is a very good proxy of the ground data wherever there is no long term ground data to characterize intraday irradiance variability. A model is derived from the fitted curve and applied to the day ahead forecast based on ECMWF. Figures 3 and 4 show the application of the intraday variability to characterize day ahead forecast variability on the forecast for two days in October 2015.

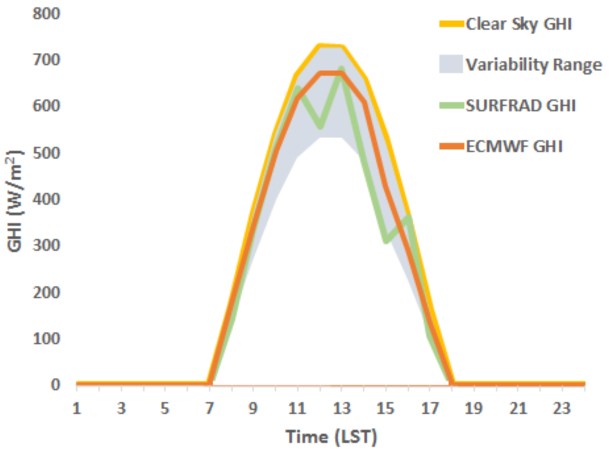

Figure 3: October 22, 2015 day ahead ECMWF forecast variability at the Desert Rock, NV site based on nominal variability derived from satellite-based irradiance data

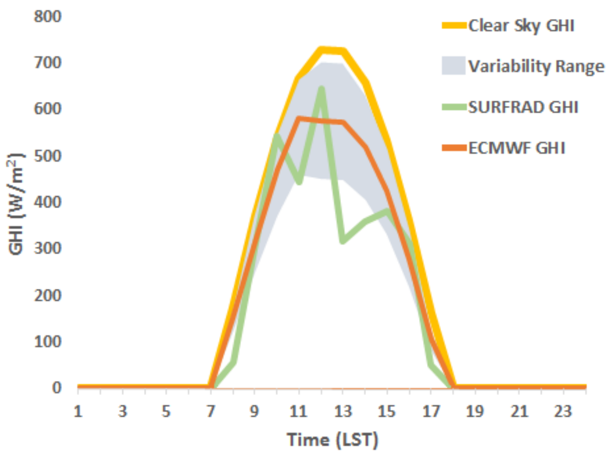

Figure 4: October 29, 2015 day ahead ECMWF forecast variability at the Desert Rock, NV site based on nominal variability derived from satellite-based irradiance data

IV. Summary

The use of satellite-based irradiance data as a valid proxy for the ground data to determine historical site-specific intraday irradiance variability has been demonstrated in this paper. These results are shown to be applicable to improving the hourly variability associated with a day-ahead NWP-based irradiance forecast. Additional work will be performed validating the ground and satellite data intraday variability connection and day-ahead forecast impacts at additional locations and NWP model day ahead forecasts around the USA.

References:

[1] P. Lauret, R. Perez, L. M. Aguiar, E. Tapache`s, H. M. Diagne, and M. David (2015): Characterization of the intraday variability regime of solar irradiation of climatically distinct locations, Solar Energy 125 (2016) 99–110

[2] R. Perez, S. Kivalov, J. Schlemmer, K. Hemker Jr., and T. Hoff (2011): Parameterization of site-specific short-term irradiance variability, Solar Energy 85 (2011) 1343–1353