Predicting Subhourly Clipping Losses for Utility-Scale PV Systems

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***Abstract* – Utility-scale photovoltaic (PV) systems are generally designed with a greater DC power capacity than their inverters are capable of converting to AC power, resulting in system clipping. Modeling tools used to forecast the generation of photovoltaic systems predict the degree to which a system is expected to clip throughout the year. However, standard PV modeling software utilizes an input of hourly meteorological data to predict these losses. For periods of intermittent irradiance in which the incident irradiance at times may cause the system to clip, an average of this irradiance over the course of an hour may result in a prediction which fails to encompass clipping losses for those intermittent intervals. Presented within this paper is a model for predicting these losses by averaging high-resolution datasets and comparing losses through the NREL developed modeling tool System Advisor Model. This prediction model utilizes freely available data through the National Solar Radiation Database to predict these losses, so the methodology presented allows users and developers to predict subhourly clipping losses at a site where minute-resolution ground data would otherwise be unavailable.**

I. Introduction

Utility-scale photovoltaic installations are typically designed with a greater DC generation capacity than the power electronic components, such as inverters, can convert to AC power. Reasons for designing systems with a DC:AC ratio greater than 1.0 include the capability of generating power at or close to the maximum AC output for greater periods of time and accounting for PV module degradation over a system's lifetime, maximizing project economics by producing energy optimally based on the cost of system components. However, the oversizing of the DC components results in losses referred to as clipping, in which the output power of the PV modules must be scaled back to prevent overloading the AC and power electronic components of the system, and to keep the project within signed power agreement limitations. While this clipping ultimately reduces the total energy provided by the system, it is often a necessary loss to maximize project economics.

Photovoltaic modeling software typically utilizes hourly datasets in order to predict yearly and lifetime generation totals for modeled photovoltaic systems. These datasets are generally good at accounting for most losses and predicted generation for a given system. However, one of the main limitations of hourly datasets are their inability to accurately predict losses which occur on a timescale of less than a single hour. One such loss that is difficult to account for on an hourly basis is system clipping losses. During periods of intermittent irradiance, the average irradiance over the course of the hour may result in a predicted plane-of-array (POA) irradiance which would not cause the system to clip, or may cause it to clip to a very minor degree. However, within that hour the system may experience periods of both very high irradiance and very low irradiance, meaning that during that period it may both clip significantly and generate a lower level of power. An average of those extremes may not predict system clipping where notable clipping is experienced, as demonstrated in Figure 1. As a result, predictions using hourly datasets have been documented to overpredict generation and underpredict clipping losses. Therefore, to more accurately predict generation for a PV installation, it is necessary to determine the level to which the system might clip beyond what might be predicted using standard one-hour resolution datasets used in industry-standard modeling tools such as PVSyst.

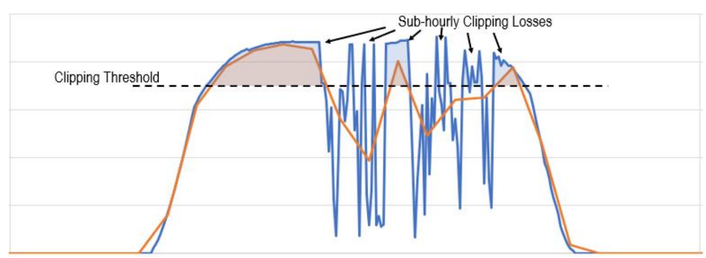

Fig. 1: Disparate clipped energy forecasts comparing a single day's POA irradiance for instantaneous 5-minute resolution data and an averaged hourly-resolution dataset

Attempts at modeling and predicting subhourly clipping losses have been made most generally by comparing minute-resolution ground data to hourly resolution satellite data [1-3]. However, ground data is rarely available at the onset of development and planning of a new PV system. This data takes time to collect, and therefore there is a need for a means to predict subhourly clipping losses in the absence of this high-resolution data. Presented in this paper is a modeling method which utilizes 5-minute resolution data provided by the National Solar Resource Database (NSRDB) to predict these losses on a site-by-site basis [4].

II. METHODOLOGY

Five-minute data for numerous sites across the United States were collected for the years 2018 and 2019 from the NSRDB. Each 5-minute dataset was averaged, centered over the half-hour of each hour, to form a unique hourly dataset. This hourly structure mimics the structure of datasets formed via other sources. At each site for which meteorological data was collected, a PV system was designed through NREL's System Advisor Model (SAM) [5]. System Advisor Model was used for these simulations because unlike other industry-standard simulations tools such as PVSyst, which at present is only capable of modeling with hourly and half-hourly datasets, SAM is capable of modeling generation with datasets of a resolution of up to 1-minute.

A single-axis bifacial tracking system was designed in SAM for each location with a power-ratio of 1.00 at the inverter, and instead was power limited at the interconnection resulting in a power ratio of 1.30 to minimize derating effects on the inverter and other electronic components due to high temperatures. An example of such a setup is shown in Figure 2. SAM reports for each simulation the clipping at both the inverter and at the interconnection as a percent of the total DC power generation. Identical simulations were performed utilizing each meteorological dataset, including at an hourly resolution and at the five-minute resolution for the years 2018-2019. The resulting clipping losses at the inverter and at the interconnection for each simulation was recorded, and the differences between the clipping losses between each hourly and corresponding 5-minute simulation were recorded as the subhourly clipping losses. These losses were averaged over years 2018 and 2019 to provide a more accurate estimation of the subhourly clipping losses, as weather variability between years often results in slightly different predicted subhourly clipping losses.

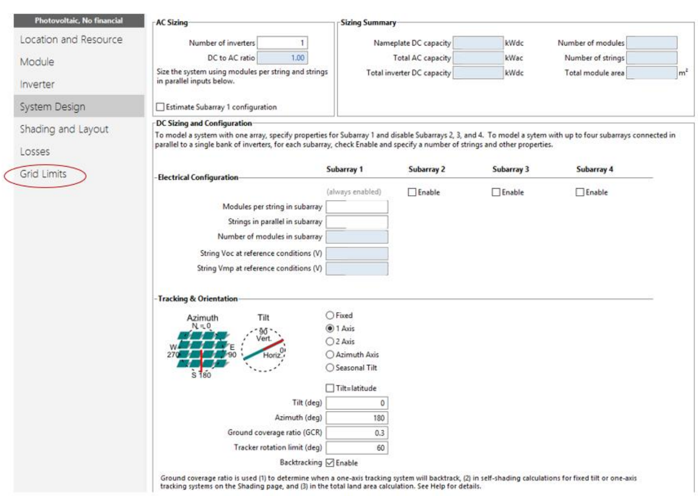

Fig. 2: System configuration through SAM interface (system specifics omitted)

Photovoltaic modules degrade over time, at an approximate rate of 0.5% per year. The degradation of PV modules decreases the effective DC:AC ratio of the system over the course of the system's lifetime. Therefore, to account for this degradation additional DC power losses were applied to each model at a rate of 0.5% for each year of operation. Simulations were repeated for years 1, 5, 10, 20, 25, and 30, as these years would provide enough data for a reasonable interpolation of losses for years throughout a system's typical lifetime.

In addition to analyzing subhourly clipping losses comparing predictions utilizing 5-minute data and 60-minute averages of that data, we explore how subhourly clipping predictions compare when hourly datasets are compiled by taking the instantaneous measurements on the hour instead of being averaged over the hour. This method, instead of averaging high-resolution datasets over the course of the hour, only used individual data points on the half-hour of every hour, omitting the other 11 datapoints over the course of the hour. These losses were also modeled throughout the system's life to analyze how the predictions vary as the effective DC capacity of the systems decrease.

III. RESULTS

For all sites selected at this power ratio, subhourly clipping ranged between 0.4% and 0.8% for the first year. Subhourly clipping is presumed to be a function of maximum irradiance, irradiance intermittency, and system design, each of which is expected to vary based on siting location. Therefore, none of these results should be considered typical for any particular site and subhourly clipping should be evaluated on a site-by-site basis.

As previously mentioned, PV modules degrade throughout their lifetime, which decreases the effective DC:AC ratio of the system. This degradation results in a decrease in the predicted subhourly clipping over time, as demonstrated in Figure 3. Notably, as the modules for these systems degrade, the subhourly clipping losses also decrease at different rates based on the site location due to the non-uniformity of clipping for each site. Therefore, not only does this necessitate evaluating subhourly clipping losses independently at each site, but it is then also necessary to evaluate these losses over time as the system degrades.

Based on the results in Figure 3, yet another interesting trend was observed, which reinforces the principle that subhourly clipping should be evaluated at each individual site. Sites with very high total irradiance, such at the site modeled in Arizona, experienced very high clipping levels overall. However, presumably due to a generally low level of weather variability, it was not among the sites with the highest overall subhourly clipping losses for the first year. The system did have by far the highest predicted subhourly clipping at the latter end of the system life, presumably because the degradation of the PV modules resulted in little clipping overall by the end of the system life for sites which had lower overall irradiance.

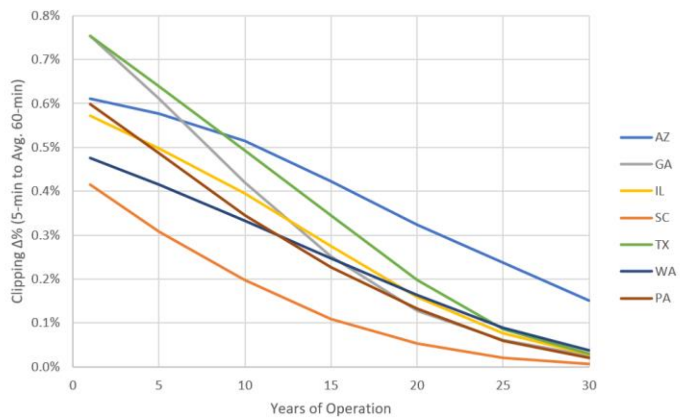

Fig. 3: Difference in clipping losses for a total of 7 sites across the contiguous US, comparing system clipping forecasts using 5-minute weather data to hourly averaged results for 2018 and 2019

To determine the effect that averaging contributed to the estimated subhourly clipping, an alternative method of compiling hourly datasets by using instantaneous datapoints on the hour instead of averaging was also tested. This method resulted in subhourly clipping comparative to the high-resolution data within a range of 0.2%, as shown in Figure 4. This result indicates that with regard to predicting subhourly clipping losses, datasets which collect data instantaneously on an hourly basis may be statistically better at accounting for subhourly clipping than datasets which average higher-resolution data over the course of an hour.

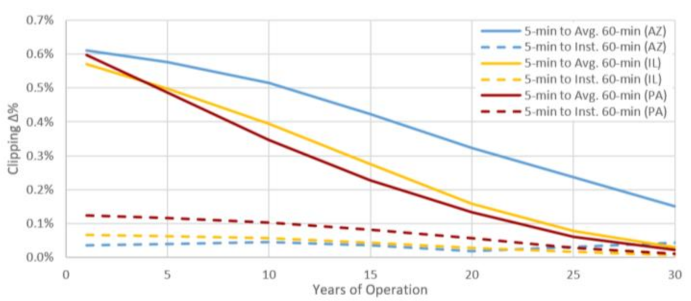

Fig. 4: Difference in clipping losses for three sites comparing reported losses using 5-min data to instantaneous and averaged hourly data

IV. Summary

Accounting for all losses present in a system is paramount for accurately modeling system generation. However, due to the limitations of standard modeling programs which utilize hourly datasets, losses such as clipping which often vary over the course of an hour are poorly accounted for using data at such timescales. While clipping is best accounted for using high-resolution data collected at the ground level, this practice is prohibitive at the onset of a site's design period. The model presented in this paper allows project designers to quantitatively account for these losses where ground data may otherwise not be available.

The results of this analysis indicate that subhourly clipping may account for losses of between 0.4-0.8% depending on a number of factors such as location, irradiance at the site, weather variability, and DC:AC ratio. These results are not expected to be typical for any site relative in location to that which was tested, and subhourly clipping should be evaluated on a site by site basis. Our results also indicated that weather files which are compiled by collecting instantaneous hourly data may result in clipping estimations more in line with that which is predicted using higher resolution data. By comparing the disparity in subhourly clipping based on hourly file composition, we also highlight the importance of understanding how data has been processed to compile hourly datasets used for modeling. The distinction between estimated subhourly clipping losses based on file composition can also inform composition methodology for solar resource providers.

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