IMPLEMENTATION OF A SUB-HOURLY CLIPPING CORRECTION IN PVSYST

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ABSTRACT: Simulating PV systems with a large DC:AC ratio in hourly steps will underestimate the clipping losses, when sub-hourly irradiance fluctuations are close to the clipping level. In a previous work [1], we developed a model to effectively correct this underestimation. The model is based on the once-only extraction of fluctuation information from horizontal plane sub-hourly weather data, which is stored together with the aggregated hourly weather data. This additional hourly data allows one to compute the sub-hourly clipping correction for any kind of PV system that is simulated with this hourly weather data.
In the present work, we describe the implementation of this model in the PVsyst software and study its impact on the simulation results in different situations.
Keywords: Simulation, System Performance, Sub-hourly, Irradiance, Clipping

1 INTRODUCTION

In photovoltaic (PV) system development and operation, hourly simulations are commonly used to estimate system performance due to their shorter run times and the widespread availability of hourly weather data. Although shorter time intervals can in principle also be simulated, hourly data remains more accessible and efficient for many applications.

However, weather conditions such as solar irradiance can fluctuate significantly within the hour, which hourly simulations may not fully capture. Studies (see references in [1]) have shown that this limitation can lead to overestimations in annual energy yields by a few percent, depending on factors like the system's DC:AC ratio and the variability of sub-hourly weather patterns.

In systems with high DC:AC ratios, sub-hourly fluctuations in irradiance may cause the DC output to intermittently cross the inverter's clipping threshold. Since hourly simulations often miss these brief but significant drops or peaks in DC output, the corresponding clipping losses are not accounted for, resulting in overestimated energy yields. Over the course of a year, these missed losses accumulate, making this effect one of the primary sources of discrepancy between hourly and sub-hourly simulations.

In a previous study [1], we have presented a model that estimates the missing clipping losses for each hour, based on 3 hourly variables extracted from the input horizontal-plane minute global irradiance data. This method allows to improve the accuracy of the clipping loss evaluation, and therefore of the whole yield simulation, all without incurring the computational cost of the minute simulation.

Our subsequent article [2] discussed the remaining bias towards higher yields when comparing hourly and 1-minute simulation. This was eventually shown to result from applying hour-based transposition models to 1-minute irradiance data. While those findings are related, this paper focuses solely on clipping corrections and does not address transposition-related discrepancies.

In the present paper, instead, we present the implementation of the sub-hourly clipping correction model [1] into PVsyst 8 [3]. First, in Section 2, we summarize the model and detail the main steps of the algorithm. In Section 3, we then illustrate the actual implementation in the software, with a step-by-step walkthrough of the main interface actions. In Section 4, we present several results obtained using PVsyst 8 with the correction model, as well as some comparisons with 1-minute simulations. Finally, we conclude with some outlooks in Section 5.

2 MODEL SUMMARY

This section summarizes the model that was implemented in PVsyst 8. For a more comprehensive explanation we refer the reader to [1, 2].

The model uses sub-hourly irradiance data, ideally at 1-minute intervals. Its core concept is to extract a set of parameters from the sub-hourly data that allow to describe the irradiance fluctuations within each hour. These parameters are then stored alongside the hourly weather data and can be used to quickly approximate the clipping losses that would have occurred in a sub-hourly simulation.

The model relies on two main simplifying assumptions. First, that the result of the simulation does not depend on the ordering of the time steps within each hour. This means that thermal inertia effects are neglected, which is justified by the temperature dependence of the PV conversion efficiency being secondary to the irradiance dependence. Second, that the fluctuations in DC power can be mapped proportionally from the fluctuations in global horizontal irradiance, for any given plane orientation.

Based on the above two simplifying assumptions, it is possible to reorder the time stamps within each hour without affecting the total yield. To characterize and model the global horizontal irradiation data within each hour, three supplementary parameters are extracted in addition to the average value: the maximum, minimum, and the number of minutes below the average value. During the hourly simulation, these parameters are used to reconstruct an approximate DC power profile for each hour, based on the corresponding average irradiance values.

One advantage of this approach is that the extracted parameters are independent of the specific PV system design or its clipping threshold. This flexibility allows the model to be applied to a wide range of systems, as it relies solely on irradiance data. Another benefit is that by recording the maximum and minimum values, the model ensures that hours with significant irradiance fluctuations, particularly those that involve clipping, are accurately represented. This prevents the loss of critical information about clipping events.

In Section 4, we show that this approach effectively corrects the clipping loss underestimation and suppresses the bias between minute and hourly simulations.

3 SUB-HOURLY CLIPPING IN PVSYST 8

While it is technically possible to run sub-hourly simulations in PVsyst to evaluate clipping losses at minute level, it is not straightforward and requires many manual steps, as this requires running several hourly simulations to represent a single sub-hourly simulation.

PVsyst 8 corrects this issue by integrating the methodology presented in Section 2, allowing a proper assessment of the clipping losses, while keeping the computation time advantage of hourly simulations. The following paragraphs explains how to use this new process in PVsyst8.

An obvious, but important, prerequisite to simulate sub-hourly clipping losses is to have sub-hourly weather data, preferably at a 1-minute time-step. The impact of longer timesteps on the clipping losses evaluation is discussed in Section 4 of this paper. To be imported in PVsyst, this data can use any usual text format (.txt, .csv, …) with one line for every time-step. Figure 1 shows an example of such data.

Timestamp	GHI	DHI	Tamb
01.01.2022 08:09	192	98	24.0
01.01.2022 08:10	195	99	24.1
01.01.2022 08:11	198	100	24.2

Figure 1: Example of Minutes Weather Data in xls format. Each line contains the timestamp, Global Horizontal Incident, Diffuse Horizontal Incident and Ambient temperature.

The steps are the following. Once the data is secured, open PVsyst 8 and click on the ***Databases*** button in the utilities menu.

In the newly opened window, under the ***Import And generate weather data*** title, click on ***Custom file*** button to open the ***Conversion of custom weather data file*** window

In the Data source section, select your weather data file by navigating in windows explorer. Change the ***Country*** and ***Site*** according to your project location. This step is especially important to ensure the proper working of the data quality check further done the process path.

You can customize the output file name and description in ***Internal file to be created***.

In the ***Conversion*** section, click on ***New*** to create a new weather convert protocol (.MEF) for your data. It opens a new window, where the user can indicate to PVsyst how to read the input data file. One of these information is the time step used in the file, as described in Figure 2

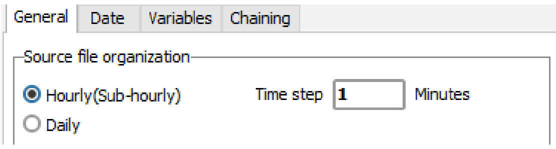

Figure 2: Custom weather conversion configuration. Indication of a sub-hourly input data file.

Up to this stage the process is strictly identical to the usual custom weather file import. Starting in PVsyst 8, a new option will be available when a time step lower or equal to 30 minutes is detected. When this condition is met, a new option will be visible in the ***Date*** panel: ***Clipping correction,*** visible in Figure 3 below.

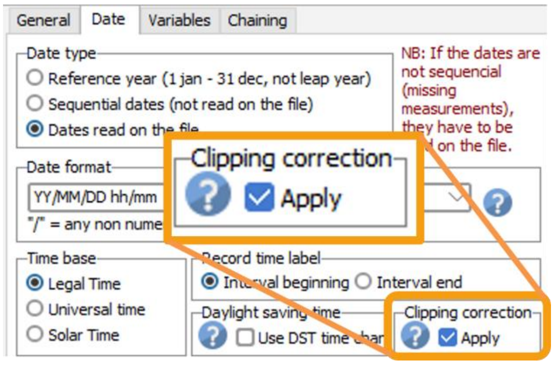

Figure 3: Clipping correction is now an option in the .MEF files.

Once everything is set-up, save the .MEF file under a new name and proceed to the conversion. During the conversion, real time information about the progress will be displayed as shown in Figure 4

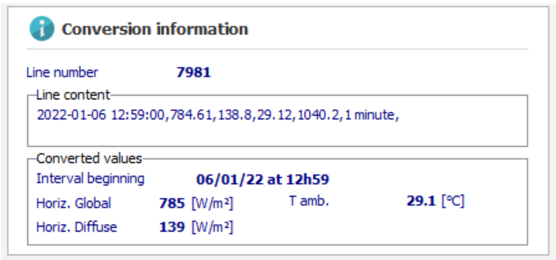

Figure 4: Text to MET file conversion process information.

As is usual after conversion, the user will be prompted to validate the imported data. With the clipping correction activated, it is possible to plot the Maximun and Minimun GHI as well as the time spent below the mean GHI.

The Figure 5 shows an example of the GHI minutes fluctuation on a given day. Between 11 and 12 am the mean GHI value was around 720W/m^2, but went as low as 200W/m^2 and as high as 800 W/m^2.

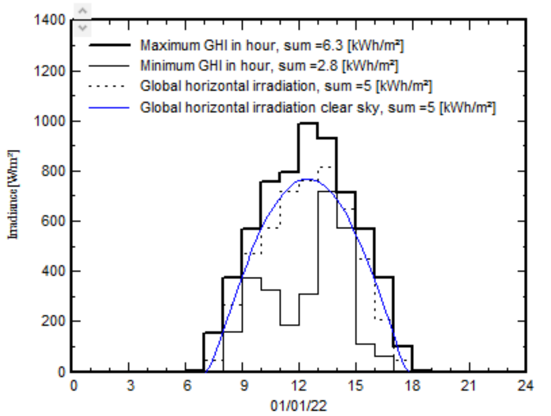

Figure 5: Minimum, maximum and hourly GHI against clear sky model for a given day.

Once the data has been checked, the normal simulation process can be applied once again. Start a new grid-connected project and select the newly created weather data file (.MET) from the database. Once the PV system is designed, run the simulation. Since PVsyst's sub-hourly clipping correction model does not require a minute-level simulation, the impact on the computation time is extremely low, and remains comparable to the standard hourly simulation.

Whenever sub-hourly clipping occurs, additional information will be displayed in the Sankey diagram representing the system losses, as visible on Figure 6.

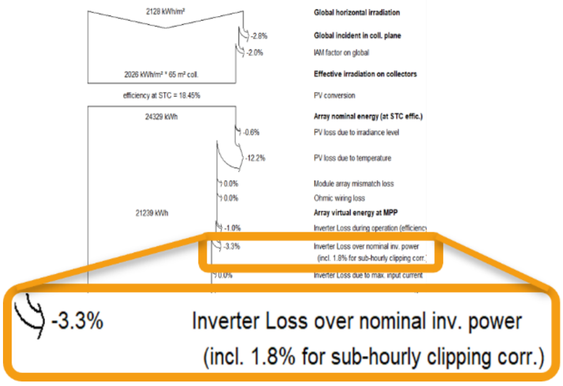

Figure 6: Additional sub-hourly clipping losses in the losses diagram.

It is also possible to configure the results export into a CSV file to include the sub-hourly clipping details. To do so, open the ***advanced simulation*** menu and click on the ***Output file*** button. In the simulation variable list, under the Inverter section you will find the "***IL_PmXSH***" variable as visible in Figure 7.

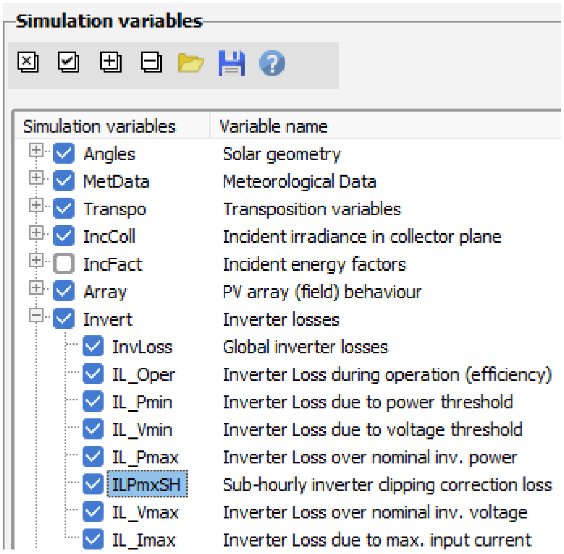

Figure 7: Sub-hourly additional clipping losses can be selected in the simulation variables for the export.

The approach in PVsyst 8 allows for an accurate to sub-hourly clipping correction with minimal changes to the usual simulation process and similar computation times as in hourly simulations.

4 VALIDATION AND MODEL RESULTS

4.1 Validation

The clipping correction model, implemented as a post-processing step for PVsyst 7 simulation results, has already been fairly validated in [1, 2]. We do nonetheless present an updated set of results, many of which are akin to those from our previous work. The two main differences are the integration of the model in the extensive codebase of PVsyst, and the slight change in some simulation results due to the improvements and corrections between PVsyst 7 and PVsyst 8.

The input data used for our validation is identical to that of [2], i.e. we use 1-minute measurements of global horizontal irradiance (GHI), diffuse horizontal irradiance (DHI), and ambient temperature, from four stations in the U.S. listed by the NREL Measurement and Instrumentation Data Center (MIDC). The station characteristics are summarized in Table 1, and we refer the reader to [2] for more details on this choice. For all stations data for the year 2020 was used.

Table 1: Site location and climate for the sources of weather data used for the validation.

Site key, state	Climate	Ref.
NRELSRRL, US-CO	semi-arid continental (BSk)	[4]
UniOregon, US-OR	warm-summer Mediterranean (Csb)	[5]
Hawaii, US-HI	tropical semi-arid (BSh)	[6]
Lafayette, US-LA	humid subtropical (Cfa)	[7]

The PV systems defined in PVsyst consist in four different DC nominal capacities, 9, 12, 15, and 20 kWp, and seventeen fixed orientations, as in [1], The inverter nominal power is 9kVA. For the model validation we vary the DC:AC ratio simply by considering a different DC capacity. When averaging over multiple scenarios or climates, we have given the same weight to all cases.

To validate the model, we first evaluate whether the model can reproduce minute-level clipping results. To this end, we compare in Figure 8 the corrected clipping losses from the hourly simulation (in PVsyst, variables "***IL_Pmax + ILPmxSH***" to the minute level evaluation of clipping ("***IL_Pmax***"), aggregated over each hour. The correction leads to a sizeable improvement in terms of the mean bias error, reducing it from 3.28% of the nominal AC power to a mere -0.12%. The standard deviation while comparable is also slightly improved (5.22% to 3.7% of the nominal AC power).

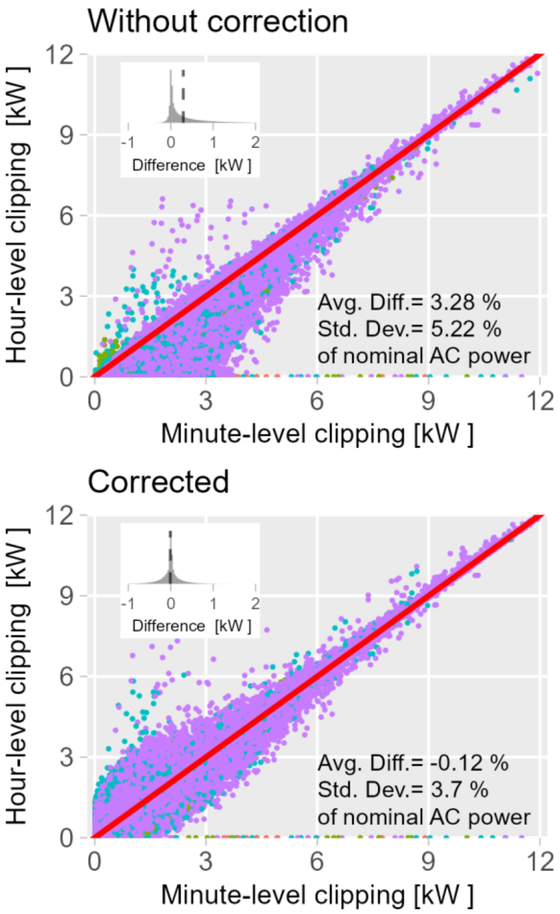

Figure 8: Comparison of hourly simulation clipping losses to the clipping losses obtained with a minute simulation. Each point represents an hour with clipping in either the hourly or minute simulation, each based on the weather data from Table 1 and the ensemble of situations described in Section 4.1. The top graph shows the case without the sub-hourly clipping correction, and the bottom graph adds the correction model to the simulation.

As in [1, 2], we also compare the resulting yearly AC energy (in PVsyst "***EOutInv***"), as given by the hourly simulation, to the same quantity aggregated from the minute simulation results. This comparison is shown in Figure 9 for the cases with and without correction. The average discrepancy is often reduced to less than a 1%. The distribution of the hour-minute discrepancy after correction is not sensitive to the DC:AC ratio anymore. This hints at the remaining discrepancy not being a result of (sub-hourly) clipping. As shown in [2], the remaining discrepancy between minute simulation and the corrected hourly simulation is rather attributable to incorrectly applying the Perez or Hay transposition procedures to the minute simulation. This does also create a bias in the minute simulation. While [2] suggests a method to correct this latter minute transposition bias, we decided not to use the procedure here since some questions remain to be addressed regarding the transposition of the direct component of irradiance.

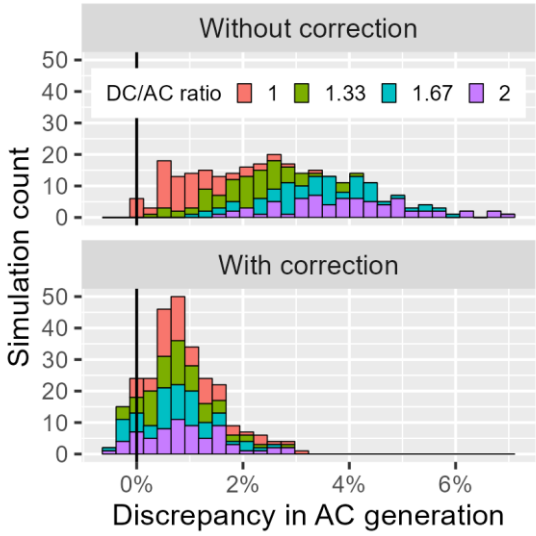

Figure 9: Histograms of the discrepancy between minute simulation and hourly simulation AC generation. Each count in the histogram corresponds to a one-year simulation using one instance weather data from Table 1, and one of the different system definitions described in Section 4.1. The AC generation, sensitive to clipping, has been corrected in the bottom histogram with the sub-hourly clipping correction presented in this work.

To further illustrate the robustness of the new implementation in PVsyst 8, we compare, in Figure 10, the yearly modeled sub-hourly clipping loss, simulation by simulation, to the results of [2].

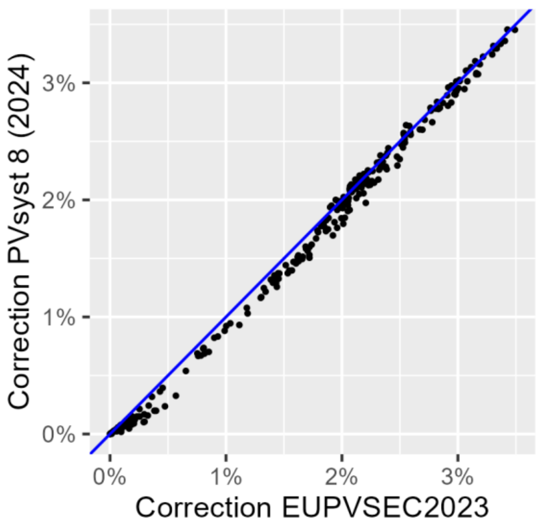

Figure 10: Comparison of the yearly sub-hourly clipping correction relative to the DC energy, as implemented in PVsyst 8, to the prototype presented in [2].

4.2 DC:AC ratio and time resolution dependencies

To further explore the possibilities of the model implemented in PVsyst 8, we run a new series of simulations with more granularity in terms of DC:AC ratio and time resolution. The simulated system has backtracking single-axis trackers with a ground coverage ratio (GCR) of 45.5%. Their axis is along the North-South line. In PVsyst we have chosen orientation "***Unlimited trackers***". The DC array capacity is 9 kWp.

The first factor, i.e., the DC:AC ratio, is varied by setting different clipping levels at the inverter. In practice, this is realized in PVsyst by choosing a grid injection threshold, then reflected in the simulation as a new maximum AC power instruction. The results are summarized in Figure 11. As could be intuited, the general trend for low ratios is that the higher the DC:AC ratio, the higher the sub-hourly clipping effects. However, this trend does saturate for very large DC:AC ratios, and the sub-hourly clipping may then even decrease when increasing the ratio. This can be understood as most fluctuations remaining above the clipping threshold, which means that the hourly average remains a good approximation in terms of clipping. It is evident that the saturation point depends on the climate, as exemplified by the results for Hawaii with a peak at about DC:AC = 1.5.

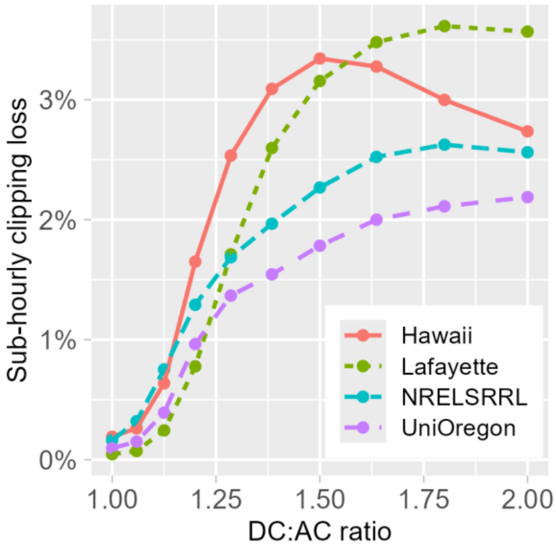

Figure 11: Sub-hourly clipping losses using the measured 1-minute data from the four sites shown in Table 1. The system that was simulated is a backtracking array with varying DC:AC ratio, described at the beginning of Section 4.2. The supplementary clipping losses will reach a saturation point that depends on the climate, but overall, for typical systems a correction between 0-3% can be expected.

To vary the time resolution, we use as baseline the 1-minute data, and then create multiple summaries of the same data by averaging at different time resolutions. For this set of results, we only used data from Lafayette; therefore, they may be considered a set of preliminary results. These results are summarized in Figure 12. Here, we find that the clipping correction at different time resolutions for the Lafayette site is seemingly modulated with a factor $\log \nu$, where ν is the sampling frequency. However, this may be a specific feature of the frequency spectrum of this specific data sample.

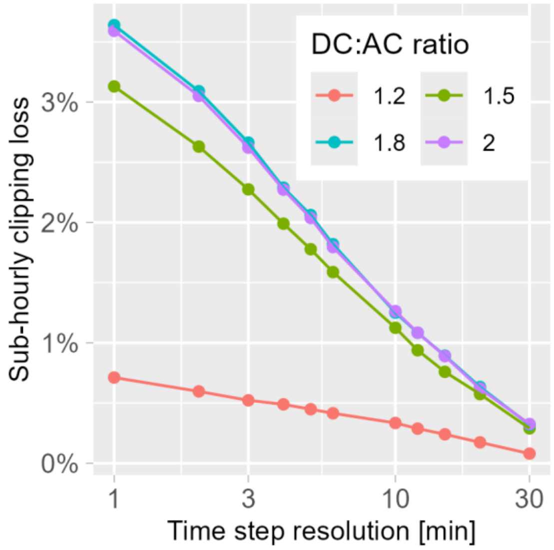

Figure 12: Time step dependence of the sub-hourly clipping correction. The time step resolution is shown with a logarithmic scale. Data for Lafayette (see Table 1) was summarized at different time resolutions, and then imported in PVsyst with the sub-hourly clipping correction option. This has the effect of averaging out the extreme fluctuations, which reduces the modeled clipping losses. Note that the dependence towards the sampling frequency $\boldsymbol{\nu}$ or inverse of the resolution follows a $\boldsymbol{\log \nu}$ trend.

It should also be noted that the measurements we used are single pyranometer measurements. In other words, they are representative of a single location. However, the response of the DC array is rather related to the irradiance received over its whole surface. Even accounting for mismatch effects, spatial averaging will reduce the intensity of sub-hourly fluctuations. The question of the time resolution is therefore linked to the spatial distribution of irradiance as well. When dealing with high frequency data, therefore, it is important to question whether the data is representative of the DC production. One option to circumvent this issue could be to employ an array of pyranometers covering the same area as the DC array.

4.3 Synthetic data

The correction model relies on sub-hourly data, ideally 1-minute data, or at least a sampling frequency that matches the variations in power of the DC array. Arguably the most reliable source for high frequency data are ground measurements. However, in practice, it can be difficult to obtain this data, especially during preliminary design phases for the PV system. One possibility is to rely on a synthetic generation procedure. This type of approach allows to generate sub-hourly fluctuations from a lower sampling frequency input. For example, one can use typical statistics for sub-hourly data to complement satellite data, which is found generally in 15-minute time steps. The result of this procedure is a high frequency time series that matches the original measurements up to a certain time scale (e.g. 15 minutes for satellite data). We refer the reader to [8], e.g., for a more thorough discussion on this subject.

Since the clipping correction can utilize any sub-hourly time series, as a proof of concept, we use here the hourly averages for the data obtained from Table 1 and utilize such a synthetic procedure to generate a 1-minute time series. The results are summarized in Figure 13, compared against those from Figure 11, where the original time series was used.

From these preliminary results we can extrapolate that the synthetic generation methodologies may induce further biases. Indeed, in the example we have studied, the clipping correction extracted from the synthetic data is lower for all four sites and for all DC:AC ratios.

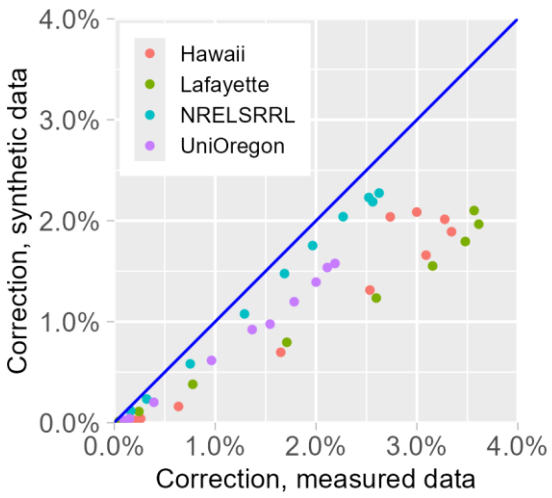

Figure 13: Comparison of the yearly sub-hourly clipping correction, using the measured 1-minute data from the four sites shown in Table 1. Synthetic data was obtained by first summarizing the 1-minute data and then using a synthetic generation algorithm to recover a 1-minute time series. The synthetic generation does not always fully reproduce the statistical characteristics of the irradiance fluctuations, and in this case the corresponding sub-hourly clipping correction is under-reported.

5 CONCLUSION AND OUTLOOK

This work presents the implementation of a sub-hourly clipping correction model in PVsyst, designed to address the underestimation of clipping losses in PV systems with high DC:AC ratios in hourly simulations. The model leverages sub-hourly irradiance data, significantly reducing the overestimation of system yields while retaining the computational efficiency of hourly time steps. By accurately modeling the clipping losses, especially in systems with large DC:AC ratios, the approach provides more reliable performance estimations.

Validation results confirm that the sub-hourly correction improves the alignment between hourly and minute-level simulations. The mean clipping losses without correction show a significant overestimation (mean error of 3.28%, standard deviation 5.22%), which is dramatically reduced after correction (mean error -0.12%, standard deviation 3.7%). This validation, based on a (roughly) two-thirds reduction in the discrepancy between hourly and minute simulations (see Figure 9), highlights the effectiveness of the implemented method.

The results further illustrate how sub-hourly clipping losses vary across different scenarios. The correction is highly dependent on factors such as irradiance patterns, local climate conditions, and the DC:AC ratio of the system. Importantly, the amount of correction does not necessarily only depend on the DC:AC ratio, indicating that other factors, such as site-specific irradiance fluctuations, also play a critical role.

While the sub-hourly clipping correction model enhances the accuracy of PV performance simulations, several areas for future improvement remain. First, as highlighted in [2] the non-linearities introduced by the transposition of direct irradiance must be addressed, particularly for systems with complex orientations, such as vertical East-West bifacial arrays. This is a critical issue as errors in the transposition of direct irradiance are prominent at specific times of the day, such as during sunrise and sunset, when rapid changes in sun position led to larger inaccuracies.

The model is sensitive to high-frequency irradiance fluctuations, but we noted that the data, when coming from a single measurement location, may not fully represent the fluctuations of DC power. This means that special care must be taken when selecting weather data for specific project designs, including accounting for spatial averaging effects.

Further work is also required to optimize the model for diverse climates and orientations, ensuring its robustness across a broader range of conditions.

Future developments should also focus on expanding the dataset used to refine the Perez transposition coefficients to be used for minute simulations, presented in [2], allowing for better statistical significance and broader applicability of the correction model. Additionally, further adjustments to the sub-hourly correction model could be explored to handle edge cases where sub-hourly irradiance fluctuations have a disproportionate effect on system performance.

6 REFERENCES

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