Impact of PV modules degradation on inverter clipping losses

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Introduction

Historical sub-hourly satellite-based solar model data in a photovoltaic (PV) system simulation provides the opportunity for analysis of long-term effects in a PV system. This study analyzes the impact of PV module performance degradation on variability and amplitude of inverter clipping losses (CLs) occurring during the expected lifetime of a PV power plant.

Methodology

The analysis of results focused on CLs and PV power output (PVout). Considered technical setups:

- Simulations used multi-year time series (TS) and typical meteorological year (TMY) satellite-based data with 1-minute and 15-minute time resolution for different sites (Table 1).
- A fixed-mounted PV system was used, featuring a Ground Coverage Ratio (GCR) of 40 %, 400 Wp modules, and 330 kW inverter. The system had two configurations: 411.6 kWp (DC/AC ratio = 1.25), 499.8 kWp (DC/AC ratio = 1.5).
- Degradation was modeled in the simulated dataset as 0.8 % at the end of the 1st year and 0.5 % at the end of the following years (with gradual degradation during the year) via the following methods:
  - Using TS with degradation for 26 or 18 years (depending on the site).
  - Repeating TMY 26 or 18 times (depending on the site) with degradation applied for each subsequent year.
  - Using post-processing: applying degradation of the long-Term Average (LTA), the currently used practice, determined from the simulations using multi-year TS.

Geographical sites	Lat. [°] / Long. [°]	Köppen-Geiger climate classification	GHI [kWh/m2]	D2G [-]	GHI VAR short [count]	PREC [mm]	PV system Tilt [°] / Azimuth [°]	TS [years]
Petrolina, Brazil	-9.0680 / -40.3190	BSh: hot semi-arid	2099.5	0.37	557.8	451.3	10 / 0	26
Wagga Wagga, Australia	-35.1583 / 147.4573	BSk: hot semi-arid / Cfa: humid subtropical	1810.8	0.29	418.0	625.8	32 / 0	18
Penang, Malaysia	5.358 / 100.302	Af: tropical rainforest	1773.9	0.52	240.4	2487.3	7 / 180	26

Table 1: Selected geographical sites with their characteristics

The impact of GHI pattern and degradation on CLs

The GHI short-term variability pattern, together with the technical setup of the power plant (mostly DC/AC ratio), affects the CLs simulation results. However, this analysis is usually only performed for the first (1st) year of PV operation. During the following years, the effective DC/AC ratio of the system is reduced due to PV module performance degradation, leading to lower CLs values.

A comparison showing an example of single day for 1st and 26th year of operation is shown in Figure 1. The presented results are based on PV simulations with DC/AC ratio of 1.25. The observed number of power values in the red area that exceed the inverter power limit is reduced in the last year. The reduction in CLs over years can easily reach 2-3% (Table 2).

Short-term changes in power are hidden when using higher time resolutions. It is crucial to consider these changes because they have an impact not only on the accuracy of the PV system performance evaluation but also on the power grid stability, power quality, and battery system design. The overestimation of PV power output that results from using different time resolutions depends on the irradiance level and the irradiance variability.

Additionally, considering of sub-hourly input data (ideally 1-minute time step) is important to achieve the highest accuracy of CLs simulation, as longer time steps can lead to a false overestimation of PV power output (Table 2).

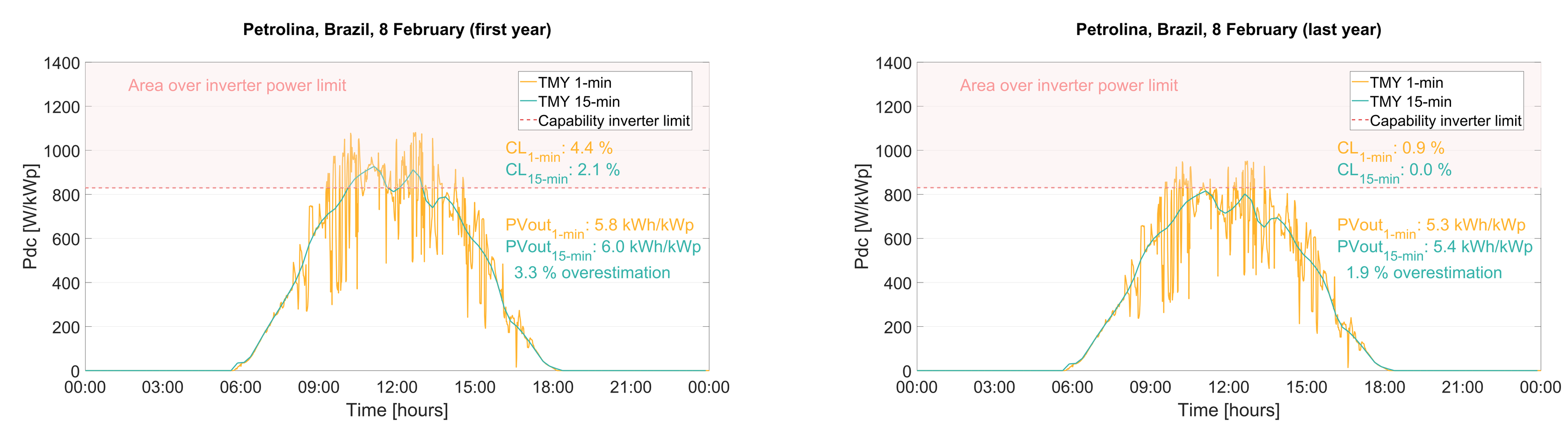

Figure 1: DC power for a selected day during the first (left) and the last (right) year of operation

	Petrolina, Brazil		Wagga Wagga, Australia		Penang, Malaysia	
	First year (1st)	Last year (26th)	First year (1st)	Last year (18th)	First year (1st)	Last year (26th)
CL, 1-min [%]	2.1	0.3	2.7	0.7	0.7	0.1
CL, 15-min [%]	1.1	0.0	2.4	0.6	0.2	0.0
PVout, 1-min [kWh/kWp]	1756.6	1578.8	1711.3	1601.6	1504.6	1336.4
PVout, 15-min [kWh/kWp]	1784.2	1592.2	1719.1	1607.7	1515.0	1340.9
Diff. between 15 and 1-min PVout [%]	+1.6	+0.8	+0.5	+0.4	+0.7	+0.3

Table 2: CLs and PVout for the entire year

Evolution of CLs over expected lifetime of the PV system

Simulations with TS and TMY in 1-min and 15-min time steps show the following observations:

- Clear underestimation of CLs in 15-min simulation is observed at all sites.
- TMY cannot realistically reproduce the interannual variability of CLs simulated by TS.
- Even if PV module performance degradation was set to be linear over years (2nd to last year set to 0.5%), evolution of the reduction of CLs over years is non-linear, mostly for less saturated PV systems (DC/AC ratio = 1.2 - 1.4).

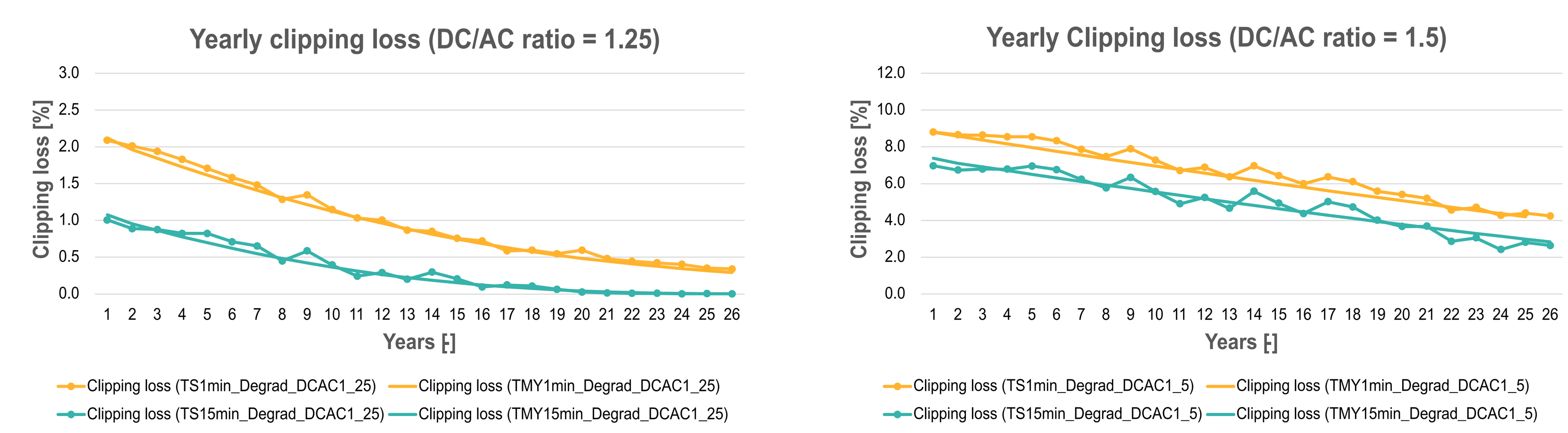

Figure 2: CLs throughout expected lifetime at different input datasets and different DC/AC ratios

The effect of clipping losses on the PV power output

Simulations with 1-min and 15-min data time steps lead to different CLs as well as differences observed in total PV output.

Even if CLs itself are not the only one contributor to different simulation results, DC/AC ratio is one of the main drivers impacting the share of simulated CLs difference in total PV output difference.

This is documented in Figure 3, where the share of CLs in PV output difference drop faster in system with DC/AC ratio of 1.25 in comparison to more saturated PV system with DC/AC ratio of 1.5 (yellowish line).

Furthermore, differences in simulated PV output in this system show higher sensitivity to interannual variability of weather (violet line).

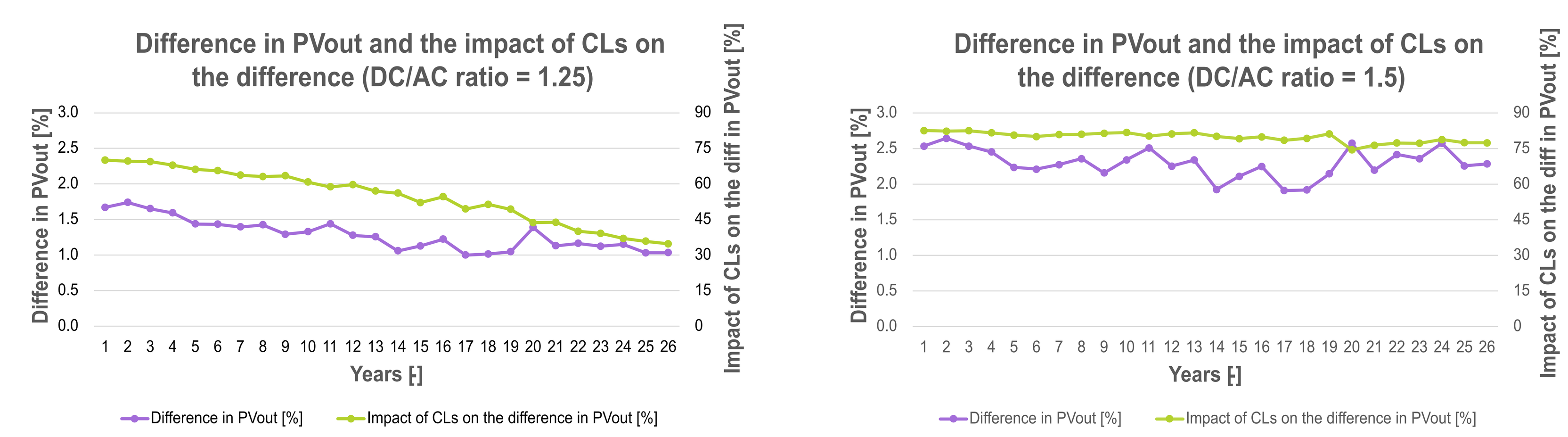

Figure 3: Difference in PVout and the impact of the difference in CLs on the difference in PVout

The impact to future yields estimation

The complex behavior observed in simulations with various data sources and time steps also affects future yields predictions. While the current standard involves a simple extension of the simulated LTA by degradation, this approach may lead to an overestimation of future yields.

The selected systems and sites in the analyzed cases showed an overestimation in future yield predictions of up to 3.6%. The range of differences varies with the site and the technical configuration. Therefore, for industry practice, the best approach is to analyze each site separately, case by case, without generalizing the results achieved in this study.

	Percentage differences in PV output [%]					
	Petrolina, Brazil		Wagga Wagga, Australia		Penang, Malaysia	
	DC/AC = 1.25	DC/AC = 1.5	DC/AC = 1.25	DC/AC = 1.5	DC/AC = 1.25	DC/AC = 1.5
TMY1min_Degrad	0.06	0.14	-0.58	-0.40	0.15	-0.61
TS15min_Degrad	1.29	2.30	0.52	0.83	0.64	1.73
TMY15min_Degrad	1.26	2.28	-0.17	0.27	0.64	0.79
TS1min_LTA_PostProcDegrad	1.80	0.25	0.89	-0.20	2.62	0.85
TS15min_LTA_PostProcDegrad	3.55	2.73	1.51	0.69	3.53	2.96

Table 3: Differences in PVout determined using different datasets compared to PVout using TS 1min

Conclusion

- PV designers should be aware of the impact of using different time resolutions of input data and the impact of degradation on CLs and energy yield.
- The impact of the difference in CLs (due to using different time resolutions of input data) on the difference in PVout is less than 100%. The choice of input data resolution affects not only CLs but all losses in a simulation chain which are nonlinearly changing due to irradiance and degradation.
- DC/AC ratio affects the difference in PVout and CLs, simulated with data using different time steps. The lower time step, the more precise simulation.
- The current industry practice using postprocessing application of the degradation on PVout calculation can lead to the difference in PVout over 3 % compared to the PVout using TS1min data and the degradation involved in the PV simulation.