Classification Method to Predict the Effect of Short-Term Inverter Saturation on PV Performance Modeling

Jonathan O. Allen¹, William B. Hobbs², and Michael Bolen³

¹Allen Analytics LLC, Tucson, AZ; ²Southern Company Services, Birmingham, AL; ³Electric Power Research Institute, Charlotte, NC, currently with SB Energy, Redwood City, CA

Introduction
Hourly PV models overestimate output by 0.5–4% due to the Average-then-Clip (AtC) bias. PV projects are generally planned using hour-averaged data from typical meteorological years to predict power and energy output. However, inverters clip power instantaneously and calculations that clip hour-averaged data will overestimate ac power output during hours in which intermittent clipping occurs. We have quantified this error, the “Average-then-Clip (AtC) bias,” using measured dc power ($P_{dc}$) and modeled inverter performance; the measurements were minute data from a test site in Birmingham, AL, which had oversized inverters and no clipping.

We then modeled the AtC bias at 9 locations using 1-minute AL, which had oversized inverters and no clipping. We then modeled the AtC bias at 9 locations using 1-minute radiation and meteorological data. These models included PV module thermal mass which we have shown is needed for accurate AtC bias modeling. The AtC bias was significant and variable, causing up to 4% overestimation of predicted energy for modeled single-axis tracking installations in humid subtropical locations with a dc:ac ratio of 2:1. AtC biases were correlated with dc:ac ratios and insolation variability and show dependence on whether a site is “fully humid” or not as defined by the Köppen climate classification.

Objective
Estimate AtC bias generally and accurately.

Method
Classify hours by radiation index and clipping potential, then average AtC bias for each subset of hours.

Results
Estimated annual AtC biases reproduce main features of measured values, with uncertainty ±16%.

Solution
This method can be used by the PV modeling community to estimate AtC bias generally and accurately.

1. Calculate annual $P_{ac}$ output for the site using TMY hourly input data and dc:ac ratio of 1:1. This is the nominal annual $P_{ac}$ output.
2. Calculate hourly clean sky radiation components using an hourly solar model.
3. Calculate hourly clean dry sky radiation, TMY meteorology, and a PV model.
4. Calculate dry sky radiation, $P_{dc}$, for each hour.
5. Calculate clipping potential, CP, for each hour.
6. For each hour, lookup average dc bias from 20-20 matrix based on $P_{dc}$ and CP.
7. Sum hourly average ac bias over the year.
8. Multiply this sum by the nominal annual $P_{ac}$ output: subtract this from the annual $P_{ac}$ output calculated using hour-scale models to correct for the AtC bias.

The average AtC bias matrices are available from the authors as a CSV file. The procedure will generate characteristic AtC bias for each hour; these may be summed to yield estimates of the AtC bias. The accuracy of these estimates for annual AtC bias are ±16%, with lower accuracy for shorter time periods. In general, historic climatological data may be used where DNI data are not available. This method may also be used to estimate AtC bias for specific installation types with improved accuracy but at a loss of generality. Matrices of average AtC bias are also available from the authors for grid-scale array and fixed-axis installations.

Conclusion
We have developed and tested a classification method to correct for the AtC bias based on radiation index and clipping potential. The classification results generally reproduce the effect of dc:ac ratio, location, and installation on AtC bias. The AtC bias estimates were themselves unbiased and matched the measured values within 50% for single year comparisons. This method may be used to estimate AtC error from hourly data, either as part of PV performance model users (e.g., Insight software), the System Advisor Model or PVWatts, or to correct the output inside of the model.

References


Acknowledgements
This work was funded by the Electric Power Research Institute.

We thank the PVPMC community for providing PVLIB software.

Classification Data

<table>
<thead>
<tr>
<th>Objective and Data</th>
<th>Estimate AtC bias generally using classification of 3.5 million hours of “observation” from 9 sites and 2 installation types.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculations</td>
<td><strong>Data</strong></td>
</tr>
<tr>
<td><strong>Classification Data</strong></td>
<td>9 sites, each 1-7 years of data</td>
</tr>
<tr>
<td><strong>Objective</strong></td>
<td>Estimate AtC bias generally using classification of 3.5 million hours of “observation” from 9 sites and 2 installation types.</td>
</tr>
<tr>
<td><strong>Introduction</strong></td>
<td>We have quantified this error, the “Average-then-Clip (AtC) bias,” using measured dc power ($P_{dc}$) and modeled inverter performance; the measurements were minute data from a test site in Birmingham, AL, which had oversized inverters and no clipping. We then modeled the AtC bias at 9 locations using 1-minute radiation and meteorological data. These models included PV module thermal mass which we have shown is needed for accurate AtC bias modeling. The AtC bias was significant and variable, causing up to 4% overestimation of predicted energy for modeled single-axis tracking installations in humid subtropical locations with a dc:ac ratio of 2:1. AtC biases were correlated with dc:ac ratios and insolation variability and show dependence on whether a site is “fully humid” or not as defined by the Köppen climate classification.</td>
</tr>
<tr>
<td><strong>Method</strong></td>
<td><strong>Classify hours by radiation index and clipping potential, then average AtC bias for each subset of hours.</strong></td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td><strong>Estimated annual AtC biases reproduce main features of measured values, with uncertainty ±16%.</strong></td>
</tr>
<tr>
<td><strong>Solution</strong></td>
<td><strong>This method can be used by the PV modeling community to estimate AtC bias generally and accurately.</strong></td>
</tr>
</tbody>
</table>

Hourly AC power output was calculated as $P_{ac} = \sum_{n=1}^{N} P_{ac,n}$, where $n$ is the number of minutes in hour $f$, the inverter model $P_{in}$, the minute dc voltage $V_{dc}$, and the number of minutes in hour $n$.

Average then Clip AC power output was calculated as $P_{ac} = \sum_{n=1}^{N} P_{ac,n}$, where $n$ is the number of minutes in hour $f$, the inverter model $P_{in}$, the minute dc voltage $V_{dc}$, and the number of minutes in hour $n$.

The error relative to nominal annual output was $\delta P_{ac} = \sum_{n=1}^{N} P_{ac,n} - P_{ac, nominal}$. Note that it is a ratio of hourly error to annual production, and so is generally less than 1%.

Classification variables include radiation scaled by dry clear sky condition $DNI$ and clipping potential $CP$.

Average scaled AIC bias, $\delta P_{ac}$, is classified by DNI Index and clipping potential.

Measurement and estimated AIC error averaged over 6 years for the S25 installation at PISU as a function of dc:ac ratio.

Comparison of measured and estimated annual AIC bias for the 1166 cases in the data set.

**References**


**Acknowledgements**

This work was funded by the Electric Power Research Institute. We thank the PVPMC community for providing PVLIB software.