Predicting the Effect of Short-Term Inverter Saturation on PV Performance Modeling

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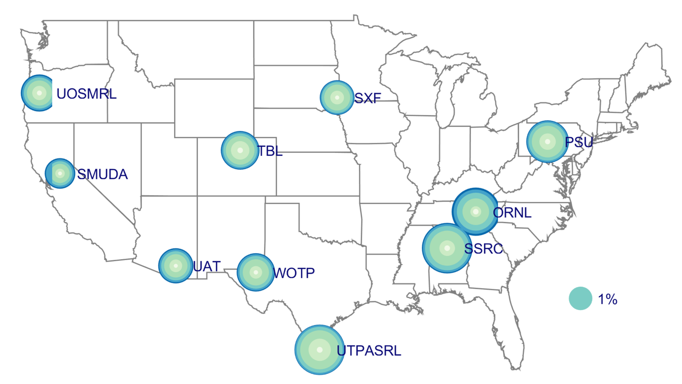
Introduction

PV projects are generally planned using performance models and hour-averaged solar radiation data to calculate hour-averaged DC power (P_{dc}) output. AC power (P_{ac}) output is then calculated using hourly P_{dc} and a model of inverter performance. Nominal inverter capacities are commonly less than the sum of the PV panels in order to reduce the cost of the PV installation. In this case some of the PV output is lost or "clipped". The inverter clips power instantaneously; therefore calculations that clip hour-averaged P_{dc} will overestimate P_{ac} output during hours in which P_{dc} is greater than the inverter capacity in some minutes and less than the inverter capacity in other minutes. We call this the average-then-clip (AtC) error and it is expected to increase with increasing DC:AC ratios and insolation variability.

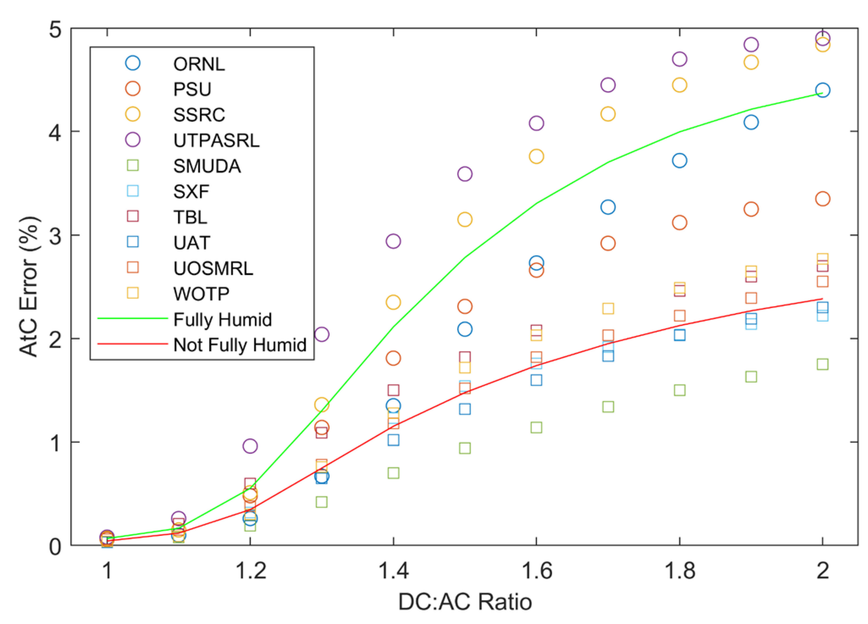
AtC errors have been reported by numerous investigators (e.g. Ransome and Funtan 2005). We have presented a multi-site multi-year investigation of AtC errors. Our approach was to determine AtC errors experimentally:

- Using minute measurement data from PV installations at one site
- Using minute solar measurements and PV_LIB at sites across the US

We then analyzed these results to determine the effect on AtC error of DC:AC ratio, PV installation type; annual, seasonal, and time of day meteorology. Results from this work show that AtC errors are in the range 0-5%, and vary with PV installation, site, and season.



Concentric circles show AtC error at the sites for DC:AC ratios = 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0.



Aggregate AtC error for 10 sites as a function of DC:AC ratio. See map above for site key.

Objective and Approach

Estimate AtC errors from hourly data like TMY3.

TMY3: hourly GHI, DNI, DHI, T, wind speed; also minute solar position, clear sky PV output, dry clean sky PV output.

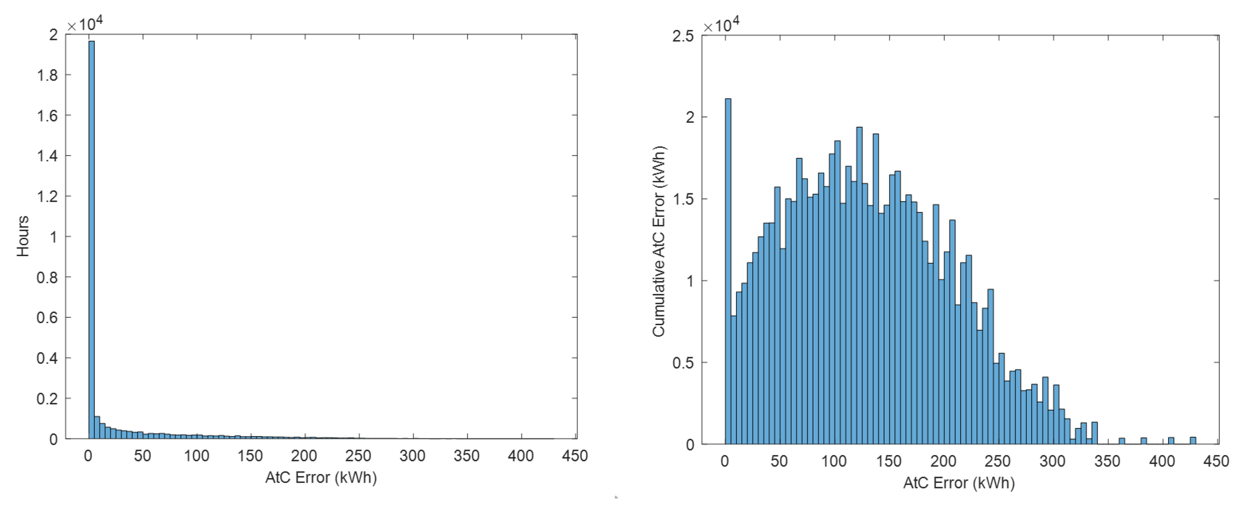
Tile minute-scale radiation based on matching hourly clearedness indices to create synthetic minute-scale data following Grantham et al. (2017). Grantham used 10 bins for DNI clearedness indices and 10 bins for GHI clearedness indices; this did not work well to estimate AtC error.

References

"Generating Synthetic Five-Minute Solar Irradiance Values from Hourly Observations", A. P. Grantham, P. J. Pudney, L. A. Ward, M. Belusko, and J. W. Boland, Solar Energy, 147:209-221, 2017.

Data Exploration

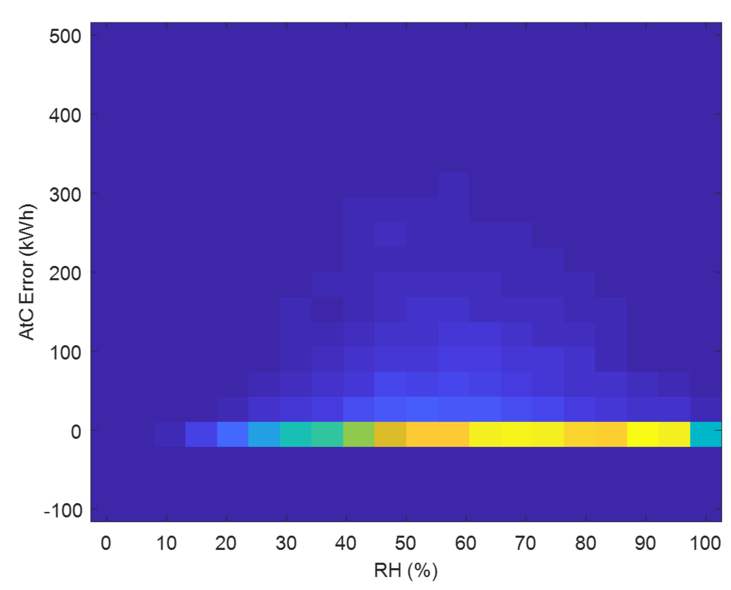
Which hours make the greatest contributions to AtC error?



Hours contributing to AtC error (left) and their contributions to the total for PSU site with DC:AC ratio = 1.5.

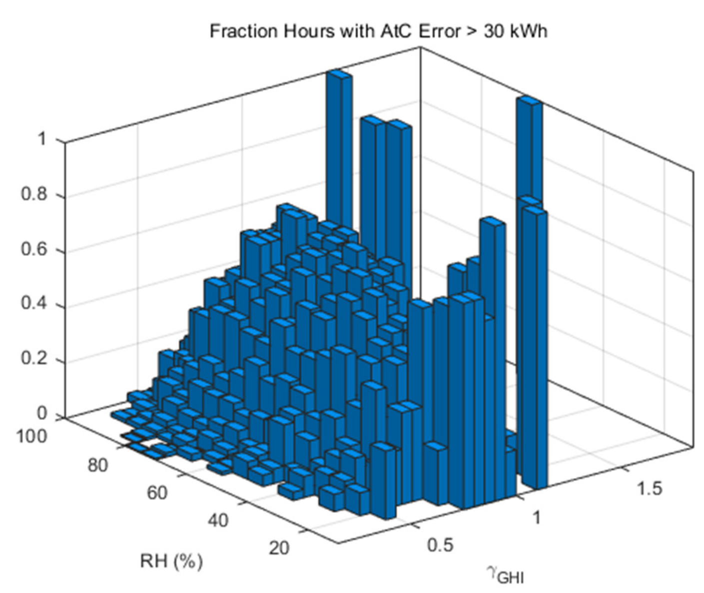
Relatively few hours with AtC Error > 30 kWh contribute most of the error.

What TMY3 data correlate with hours that contribute to AtC error?



Hourly contributions to AtC error as a function of RH for PSU site with DC:AC ratio = 2.0.

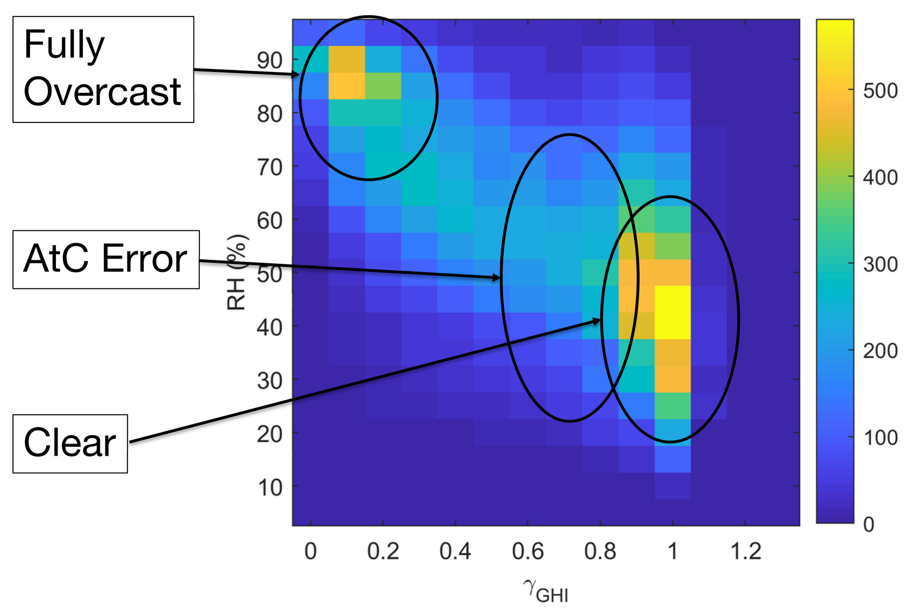
Intermediate RH correlated with AtC error contributions, likely because intermittent cloud cover is most common at these RH values; i.e. strato-cumulus clouds. But, the majority of hours contribute little to AtC Error.



Hours with large AtC error contributions classified by RH and GHI clearedness index for PSU site with DC:AC ratio = 1.5.

Discrimination of hours with large AtC error contributions is greatly improved by combining multiple dimensions. So we cluster and match hours based on RH and GHI clearedness index.

How can we segregate hours to isolate hours with AtC error?



Count of hours segregated into 440 bins by RH and GHI clearedness index for PSU site.

Simulation Results

Simulation method

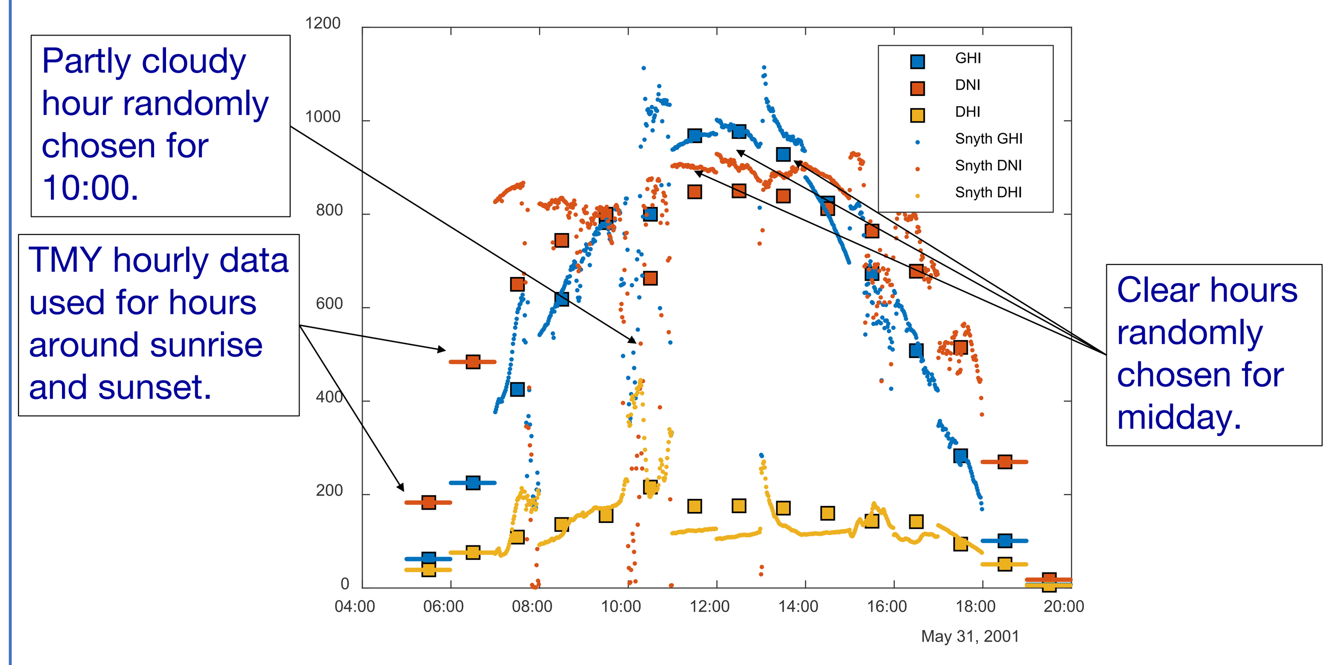
Initialize

- Scale hourly and minute GHI by dry clean sky
- Cluster historic data by hourly GHI clearedness index and RH
- Collect scaled minute data by hourly cluster

Run

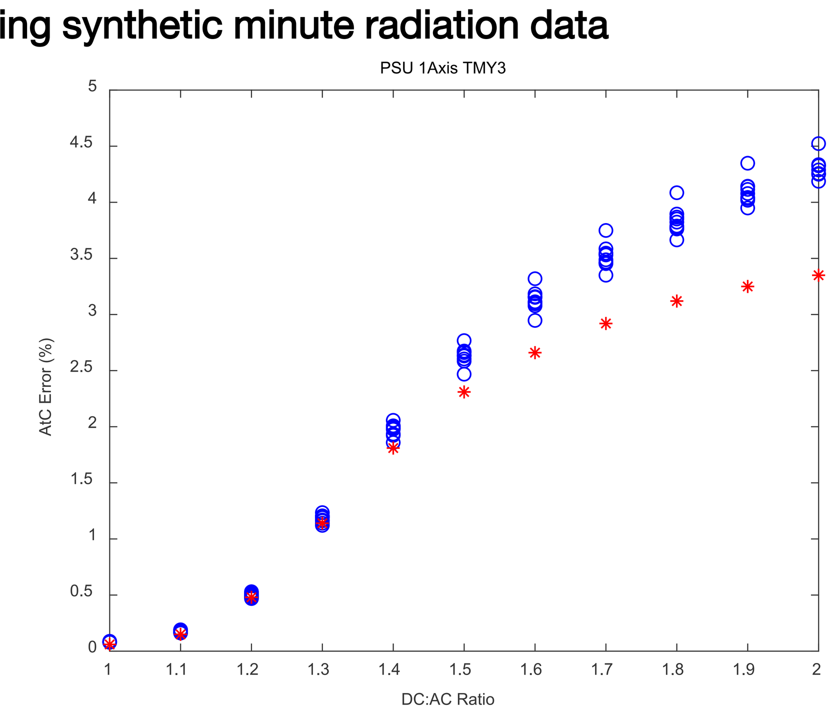
- Determine matching cluster
- Randomly select hour of scaled minute GHI, DNI, DHI from cluster
- Unscale minute data
- Calculate P_{dc} using minute radiation and hourly meteorological data

Synthetic minute radiation data



Hourly TMY3 and synthetic minute radiation data for an example day at the PSU site.

AtC error using synthetic minute radiation data



Aggregate AtC error as a function of DC:AC ratio determined from minute data (*) and using synthetic minute data (o) for the PSU site. Results from ten simulations are shown.

Conclusions

We have demonstrated a method to synthesize minute radiation data from TMY3 data using minute radiation data from the same site. Aggregate AtC error estimated using these synthetic data closely approximate AtC error based on measured minute radiation data for all ten sites.

We will test whether this method can be used to synthesize minute radiation data from TMY data for sites for which minute radiation data are not available; i.e. does our method scale with location.

Acknowledgements

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Some data provided by EPRI member companies.

NOAA SURFRAD Data

Augustine, J. A., J. J. DeLuisi, and C. N. Long, 2000: SURFRAD-A National Surface Radiation Budget Network for Atmospheric Research, Bull. of Amer. Met. Soc. Vol. 81, No. 10, pp. 2341-2358.