Distribution Function Instead of Steady-State Assumption in Time-Series Simulation

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The Problem

"Quasi-steady-state assumption" assumes constant power level over time-step which is inadequate to model:

- Phenomenon of interest to grid integration such as inverter clipping and energy export
- Phenomenon of interest to storage such as battery throughput

Possible Solutions

- High-resolution time series data (seconds)
- Machine learning or heuristics to estimate phenomenon within duration of time-step
- Distribution function to model power levels varying within duration of time-step

Distribution Function

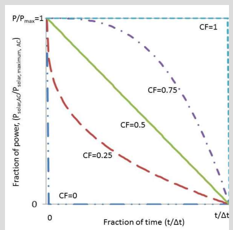
Distribution Function

$$P_{solar} = P_{solar,min} + (P_{solar,max} - P_{solar,min}) * \left\{1 - [t/T]^{\left(\frac{CF}{1-CF}\right)}\right\}$$

Maximum Power within an Hour
$P_{maximum}$ = Clear Sky Model [1]

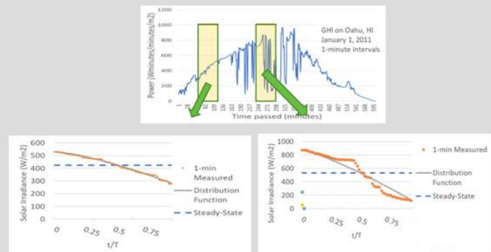
Minimum Power within an Hour
$P_{minimum} = f * P_{maximum} / AM$
f=0.045
AM=atmospheric thickness (>1)

Energy within an Hour
Shape of the distribution curve (area under curve)
CF = Capacity Factor for the Hour
CF from hourly climate data; same CF as steady state assumption



Subinterval distribution function for capacity factor: CF=0, 0.25, 0.5, 0.75, and 1.0 [3]

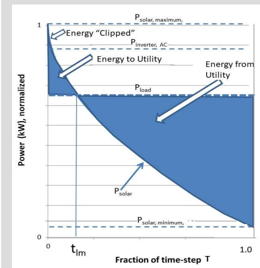
Rapidly Changing Conditions



9 a.m.–10 a.m. 1/1/11
Unimodal distribution
RMSE error distribution = 1.3%
RMSE error steady-state = 15.2%

11 a.m.–12 p.m. 1/1/11
Bimodal distribution
RMSE error distribution = 10.2%
RMSE error steady-state = 46.5% [4]

Scalar Integrals



Energy in excess of any threshold is calculated by integration (as areas under the curve) [2]:

- ***in excess of inverter capacity ("clipping")***
- ***in excess of load (export)***
- ***transformer capacity***
- ***interconnection (line) capacity***
- ***network hosting capacity***

Progress to Date

- Derived form of distribution function based on first law of thermodynamics and definition of capacity factor [2]
- Determined parameters of distribution function based on clear sky model
  - ➢ Validated for Quillayute, Washington; Athens, Georgia; and Daggett, California climate data [4]
- Piloted hourly simulation in MS Excel to demonstrate transparent calculations [3]
- Licensed and implemented in HOMER Pro Version 3.14.5 and higher [4]
- Coded Python version

New python code performs calculations related to distribution function (scalar integrals) at each time step of time series simulation. Python code by Jal Desai available for license by NREL.

Results are improved over existing methods

- Distribution function provides more accurate and useful results than existing steady-state assumption
- Error in inverter clipping estimate improved by an order of magnitude
- In the example to the right, clipping estimate using steady-state assumption is **1,030 kWh/year** which is an error of 93%, and estimate using distribution function is **13,618 kWh/year**, an error of **8%**, compared to 1-minute value of **14,789 kWh/year.**

Comparison of inverter clipping estimated using 1 hour time-step with steady state using time step durations of 1, 2, 3, 5, 6, 10, 12, 15, 20, 30 minutes and 1 hour. Example is for 1,176 kW PV system with 900 kW inverter using weather data from Oahu, Hawaii. Results generated using HOMER Pro Version 3.14.5

Future Opportunities

- License in other commercial software products
- Expand to other technologies in addition to PV (wind, battery only, etc.)
- Publish Python version on GitHub or as an API

References

[1] Meinel, Aden, and Marjorie Pettit Meinel. Applied Solar Energy. Boston, MA: Addison Wesley Publishing Company 1976. 978-0201047196.

[2] Solar Energy: Technologies and Project Delivery for Buildings by Andy Walker. Published by John Wiley and Sons Inc., Hoboken, NJ; Sept. 16, 2013; ISBN 978-1-118-13924-0. 298 pages.

[3] National Renewable Energy Laboratory Software Record 17-22, Sub-Interval Distribution Simulation (SIDSIM), 2020, by Andy Walker

[4] Walker, A., Desai, J., and Klawitter, S. "Solar Photovoltaic Systems Time Series Simulation Sub-Interval Distribution vs. Steady-State Assumption" 14th Annual Conference on Energy Sustainability, June 17-18, 2020, American Society of Mechanical Engineers (virtual conference)

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