

Combiner-Level Operational Performance Analysis Improvements

Jarrell Julien, Michael Villa, Tim Zimet | Longroad Energy

Introduction

Our improved methodology for DC performance analysis includes a performance threshold that varies as a function of irradiance, irradiance condition classification, and classification of erroneous data based on signatures of typical sensor issues. Input parameters can be tuned for each solar plant. Outputs show flagged combiners and total DC capacity categorized as "offline," "underperforming," "missing data," "stale data," or "out-of-range data."

Development & feedback process

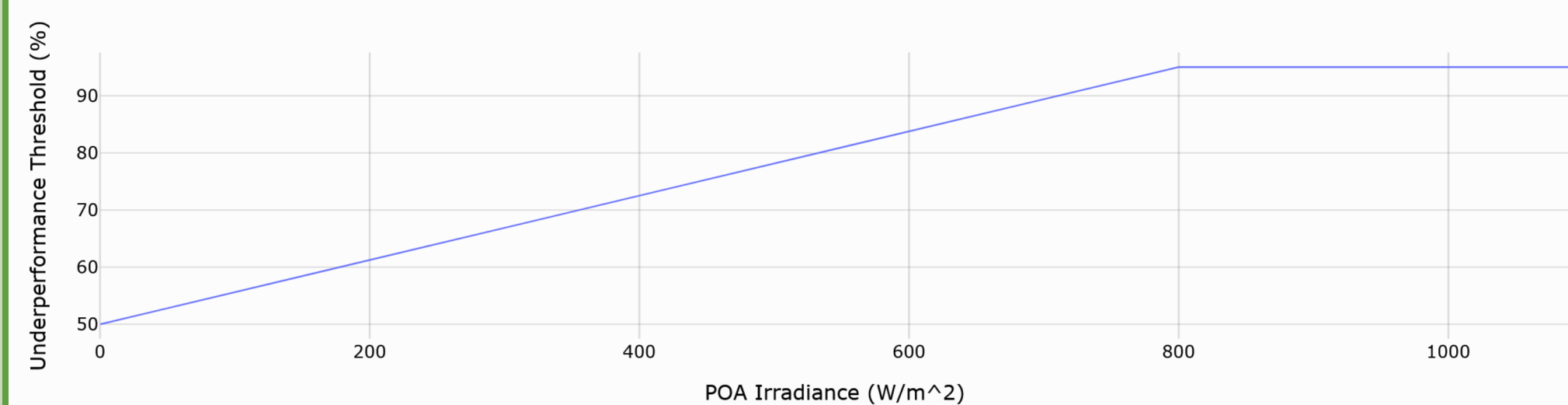
We implemented our performance analysis methodology for 15 solar projects with DC capacities between 4MW - 379MW, located across the U.S. (in California, Arizona, Texas, and Maine). The results have been presented in a daily report over the past year to operations teams, whose feedback was used for validation and improvements to the analysis.

Variable underperformance thresholds

How?

Make % underperformance threshold a function of irradiance:

$$\% \text{ Underperformance Threshold}_h = \begin{cases} (95\% - 50\%) * (POA_h/800) + 50\%, & 0 \leq POA_h \leq 800 \\ 95\%, & POA_h > 800 \end{cases}$$

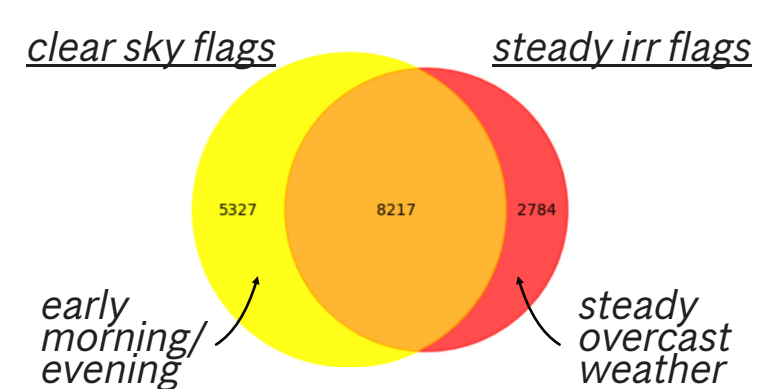


other options include: $\% \text{ Underperformance Threshold}_h = \begin{cases} 95\%, & \text{steady irradiance} \\ 60\%, & \text{variable irradiance} \end{cases}$

Irradiance

- Flag steady vs. variable irradiance by comparing 2nd derivative to a threshold.
- Site-level irradiance = median (of all sensors) when steady; minimum when variable.

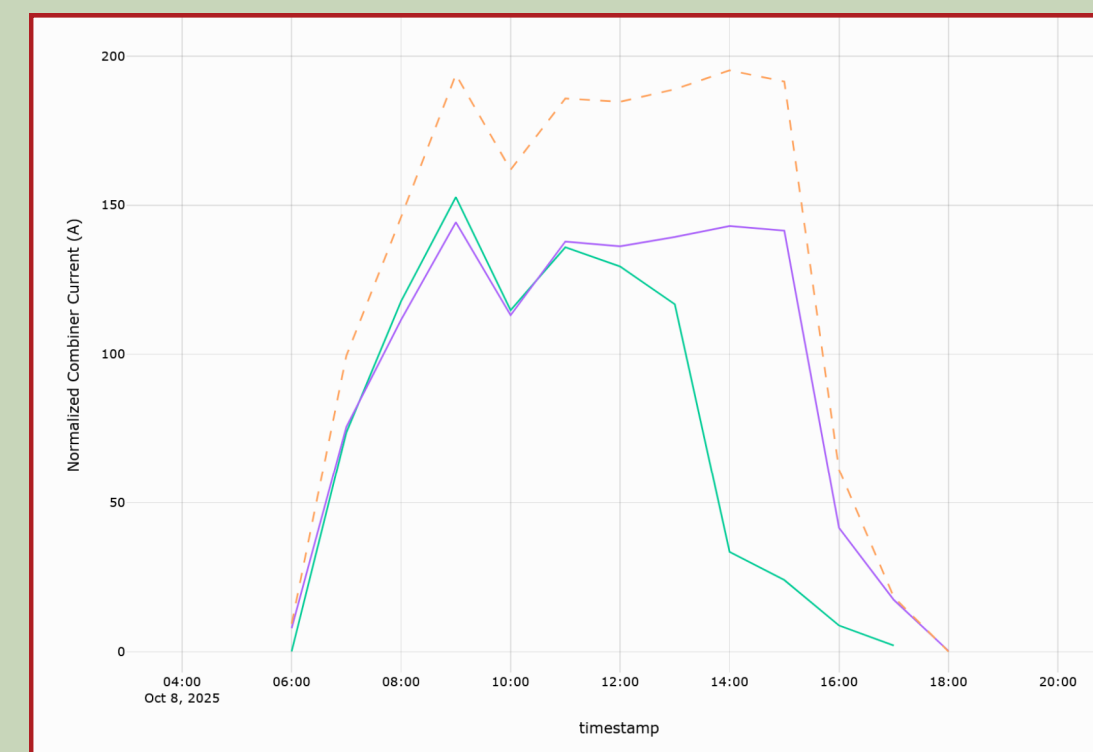
Clear sky vs. steady irr:



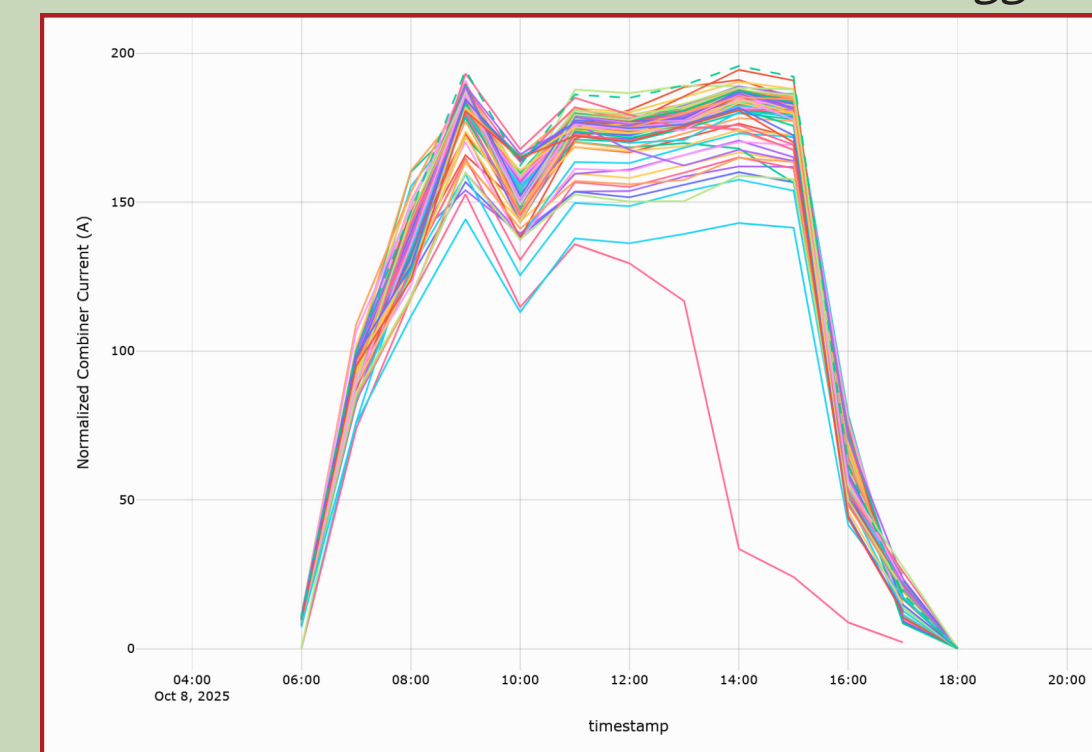
Why?

Fixed thresholds either miss underperformance or flag false positives:

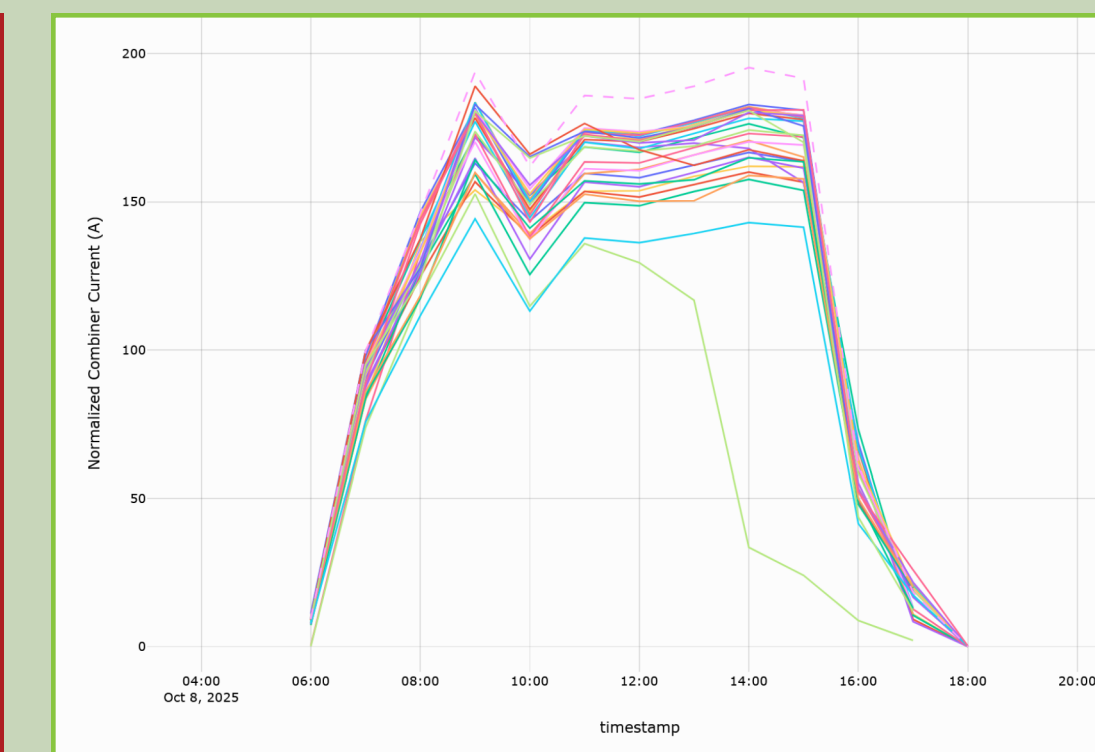
Data shown for a 199 MW DC project in Arizona on a day with max. irradiance 800-900 W/m². Dashed line = site median normalized combiner current. Solid lines = flagged combiners' normalized current.



Underperformance threshold: 80% of expected
2 combiners flagged



Underperformance threshold: 95% of expected
81 combiners flagged
(visually appears to include false positives)



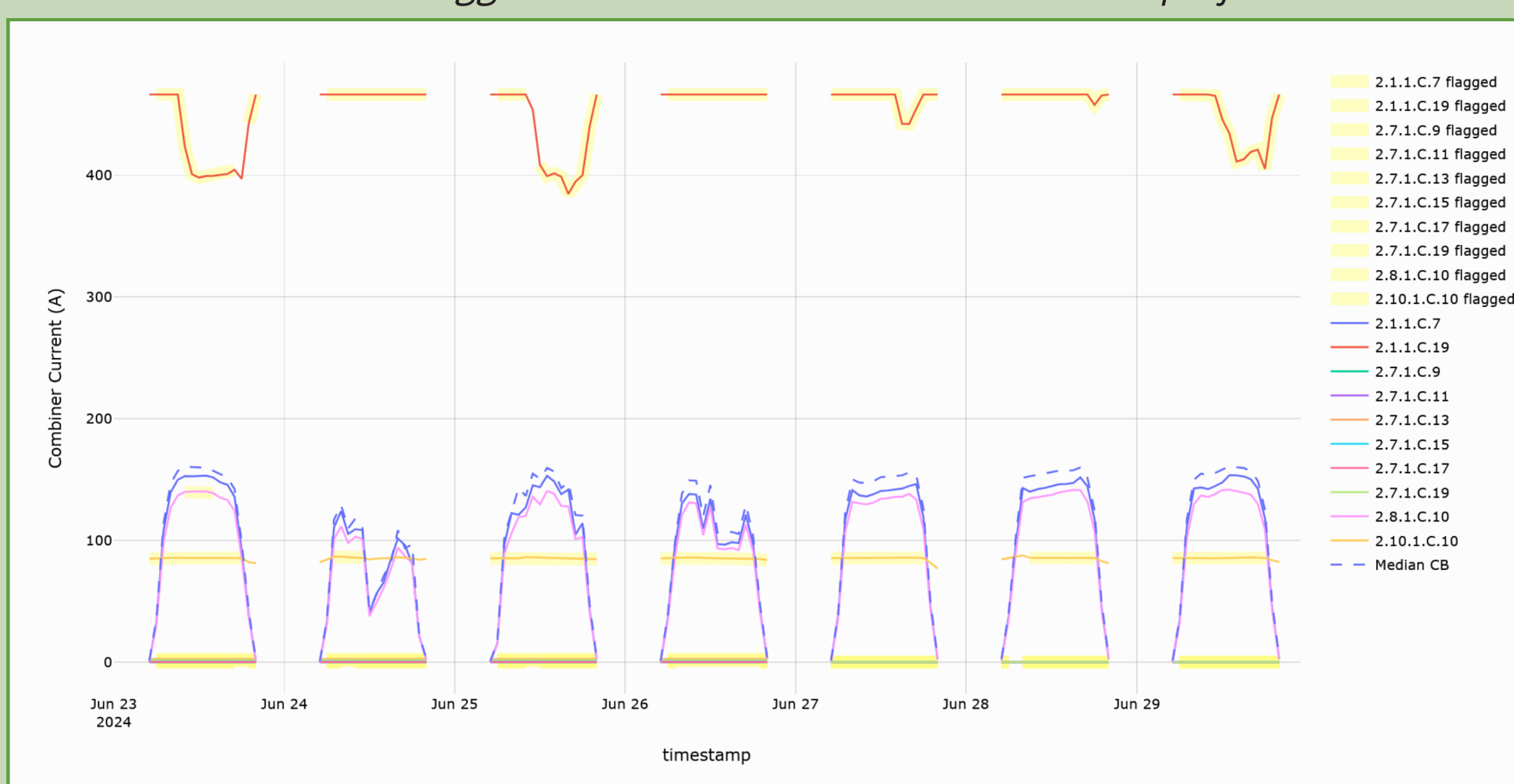
Underperformance threshold: variable %
29 combiners flagged

Erroneous data flagging

Expected issues

- Very high or negative out-of-range values / very low values: CT (current transformer) installed incorrectly or damaged
- Offset values during day and night: CT not calibrated
- No data or repeated stale values: communications/SCADA

Combiner boxes with flagged bad data shown for a 53.6 MW DC project in California.



Analysis logic: per hourly timestamp

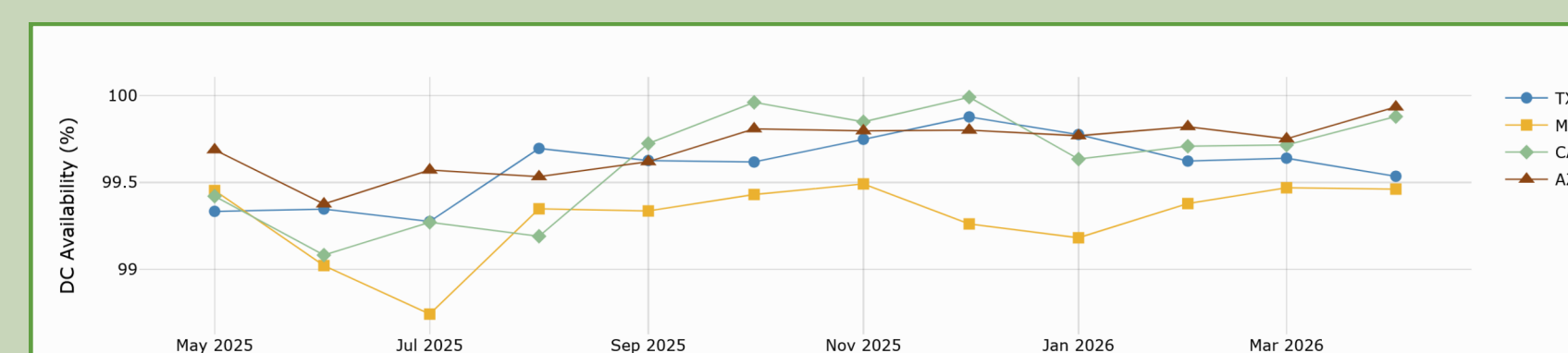
- Normalize DC CB (combiner box) currents by I_{mppt} corresponding to nominal capacity
- Flag steady vs. variable irradiance and calculate site-level irradiance
- Flag stuck/stale CB currents (change in consecutive values < tolerance, 5+ hrs)
- Flag out-of-range CB currents (normalized current < -offline threshold or > 2* I_{mppt} , 2+ hrs)
- Flag offline CBs (abs(normalized current) < offline threshold, 4+ hrs)
- Calculate "expected" CB current as 75th percentile value per inverter, excluding above flagged CBs
- Flag NaN CB current as missing, unless "expected" is NaN
- Flag underperforming CBs (normalized current < threshold * expected, 4+ hrs)
- Remove offline/underperforming flags where inverter offline or plant is curtailed

Use cases

- Help operations teams to efficiently find and correct DC equipment failures.
- Calculate capacity-based DC availability for contractual guarantees.
- Calculate KPIs for managers to track performance over time.

DC performance at Longroad

Site-wide monthly DC availability (includes offline + underperforming lost capacity) shown for 4 Longroad projects across the U.S.



Limitations

- Accurate nominal combiner DC capacities, which are used for normalization, are required.
- Precision is limited by:
 - The level of granularity of combiner box data; the smallest unit of failure is the solar module, and there can be hundreds of modules per combiner.
 - Normalization by nominal capacity does not fully capture effects of electrical wiring configuration.