ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

EU PVSEC

Use of a digital twin to detect stalling tracker events in photovoltaic power plant with horizontal single-axis tracking systems

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Overview

- Single-axis solar trackers in PV applications
- Is a stuck tracker something we should worry about?
- Detection algorithm layout
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- Validation of the algorithm on synthetic data
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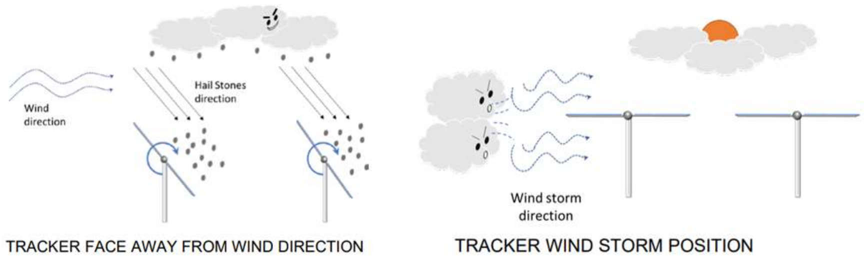
Single-axis solar trackers in PV applications

Trackers are system that change the orientation of PV modules

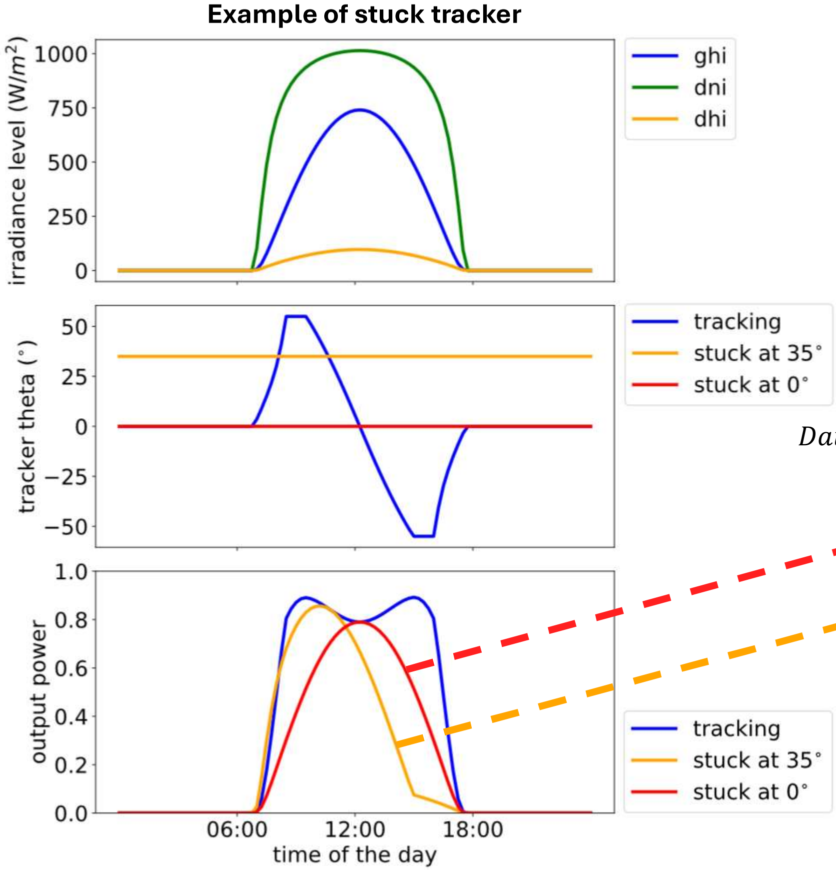
The reasons to use solar trackers are multiple:
- Protect the infrastructure, in case of heavy wind
- Protect the PV modules, in case of hailstorm
- Increase the energy yield of PV modules



Images retrieved from [1]

[1] DOI: 10.69766/JOIK1919

Is a stuck tracker something we should worry about?

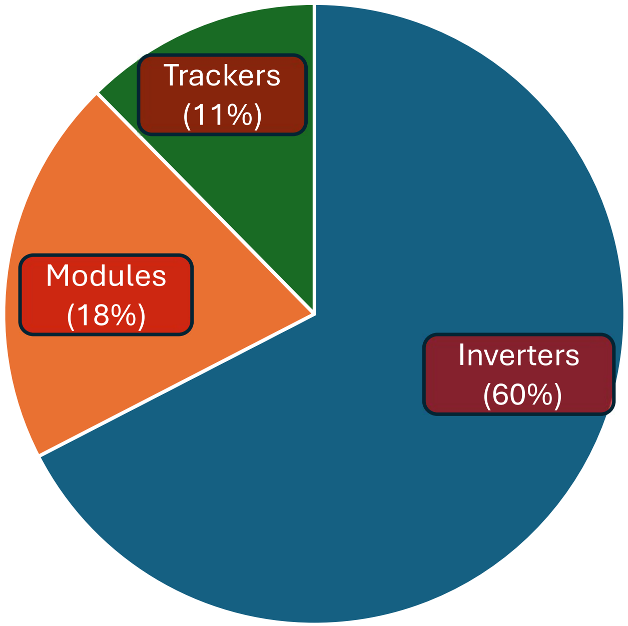


Irradiance conditions, tracker theta, and output power, in different tracking conditions: properly tracking, stuck at 35°, and stuck at 0°.

$$Daily\ energy\ lost = 100\left(1 - \frac{\sum_{day} Power_{stuck}}{\sum_{day} Power_{tracking}}\right)$$

$$Daily\ energy\ lost = 31\%$$

$$Daily\ energy\ lost = 35\%$$

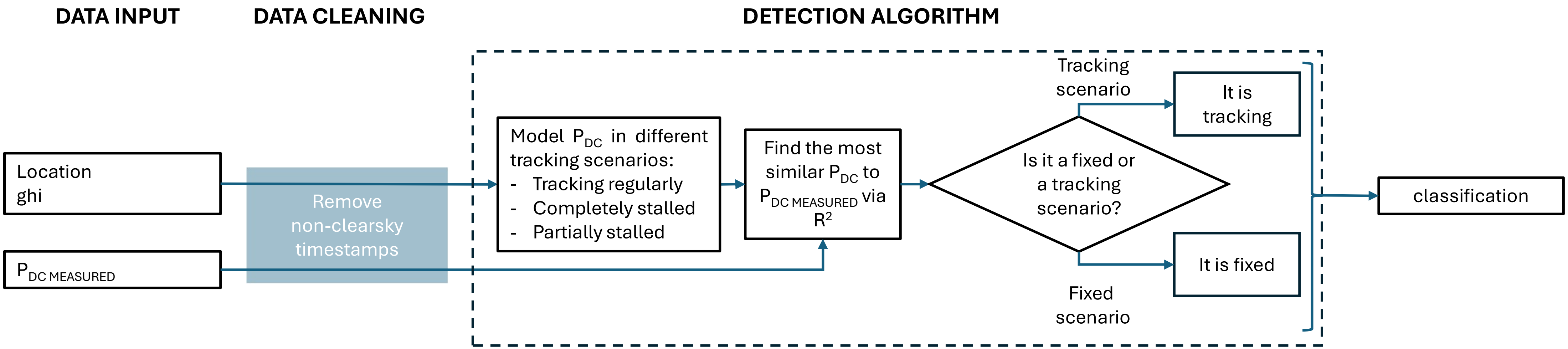


TAKEAWAY

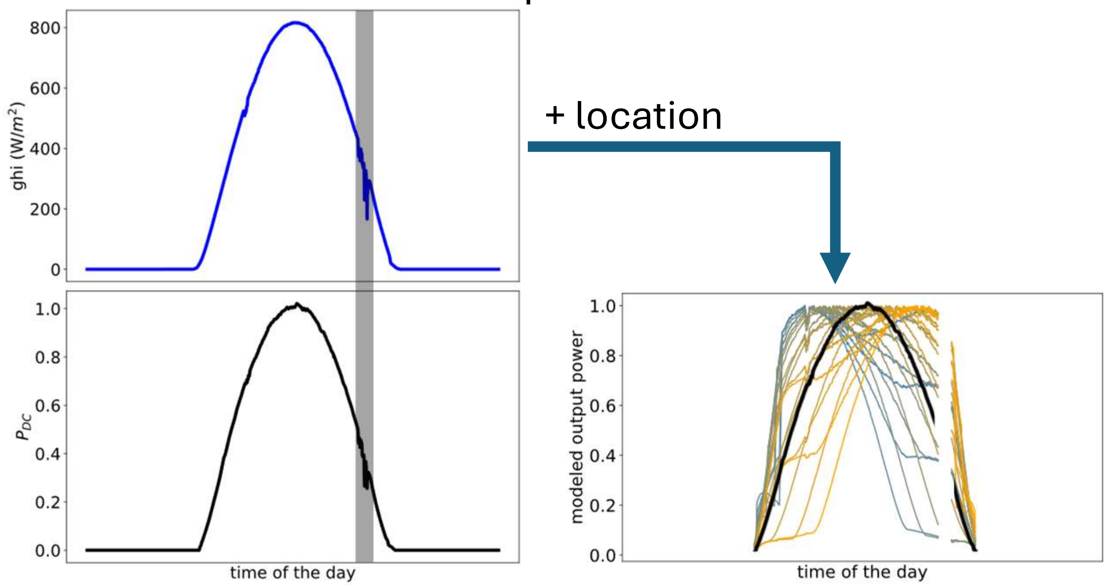
Yes, we need to address the detection of stuck trackers to avoid energy losses that reach up to 35% of the daily energy yield on sunny days. Doing so it possible to avoid accusing PV module degradation of this energy loss, hence have a clearer view about the benefits and costs of PV plants with trackers.

[1] "Past Proceedings 2024 | PVRW: Photovoltaic Reliability Workshop | NREL."

Detection algorithm layout



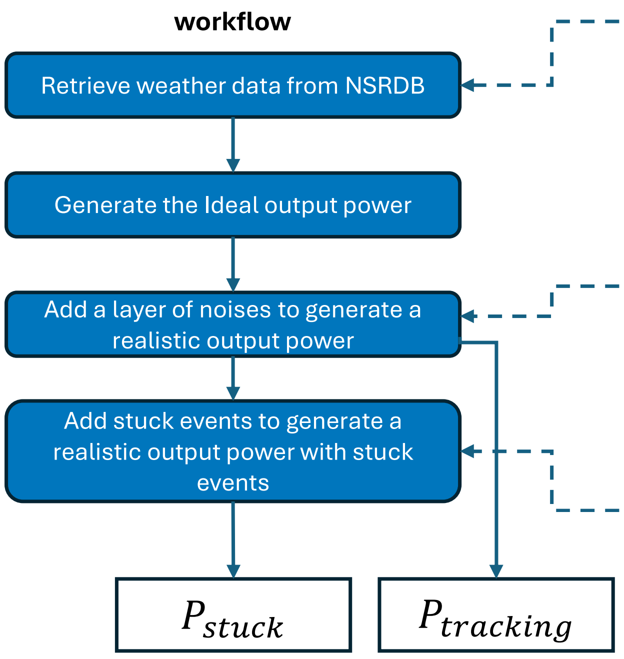
Visual explanation



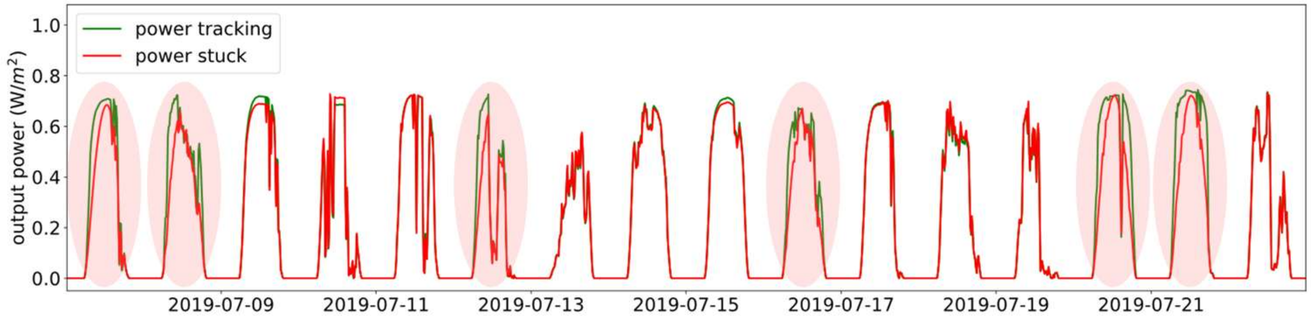
TAKEAWAY

The detection algorithm is used for data post-processing. It assumes that the gcr, the tracker algorithm, and the maximum tilt angle of the tracker, have all usual values/logics, as all of these are usually not available.

Methodology to generate synthetic data for validation



Location and system design	
Location	38 locations across US
Dataspan – frequency	4 years – 15 min
PV module Pdc0	1W, Monofacial
GCR	0.4
Albedo	0.20
Noise characterization	
Noise and soiling patterns	Random among options [4]
Degradation rate	Random among options [4]
Number string outage events	0
Inverter load ratio	1
Stuck events description	
Number stuck events	150 over dataspan
Stuck angle	0°
Duration stuck event	1 day
Permanent tracker offset	Random among options [4]



Realistic power output vs modeled power output for the case of Valdosta, Georgia

[4] NREL/TP-5K00-86459

Most of times, multiple strings feed the same combiner, so it is possible to have ''partially stuck events''. Those cases are modeled as

$$P_{out}(S) = S \cdot P_{stuck} + (1 - S)P_{tracking}$$

where S is the fraction of stuck rows, considered as

$$S = \frac{number\ of\ stuck\ rows}{total\ number\ of\ rows}$$

TAKEAWAY

Given the location, the methodology generates a synthetic dataset that is used to create a set of variants thanks to S. This is done for 38 locations across US.

Test for field data obtainment

System description

Ten rows individually measured and controlled
Current, voltage, and output power, are measured at the DC side

Experiments description

Row 3 is set at 0° for the entire day while row 8 is operating regularly.

Power combination

Power of row 3 and row 8 are first normalized per their nameplate power, than combined to create different stuck scenarios

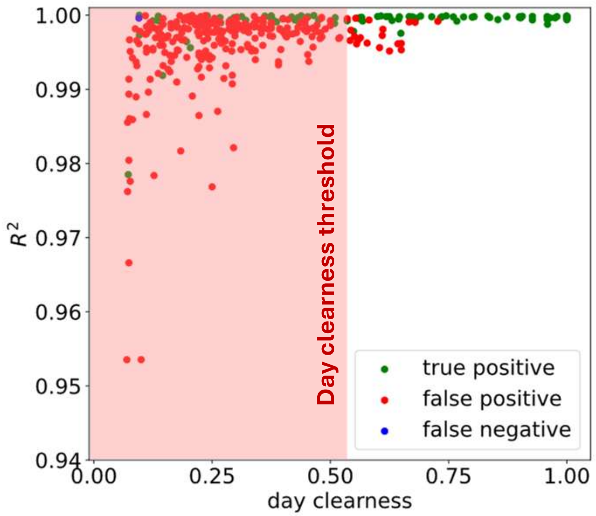
Validation of the algorithm on synthetic data

$$Day\ clearness = \frac{num(clearsky\ timestamps)^{[3]}}{num(total\ timestamps)}$$

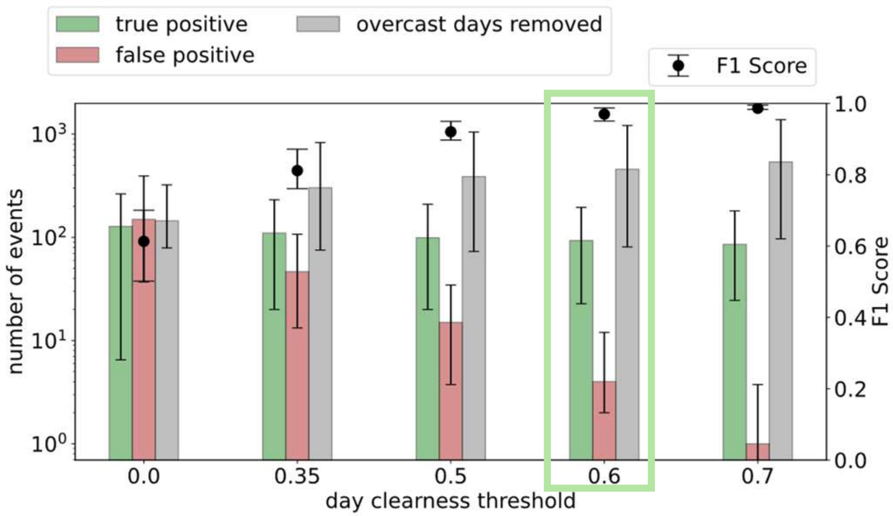
$$F_1 = \frac{2\,TP}{2\,TP + FN + FP}$$

TP True positive
FP False positive
FN False negative

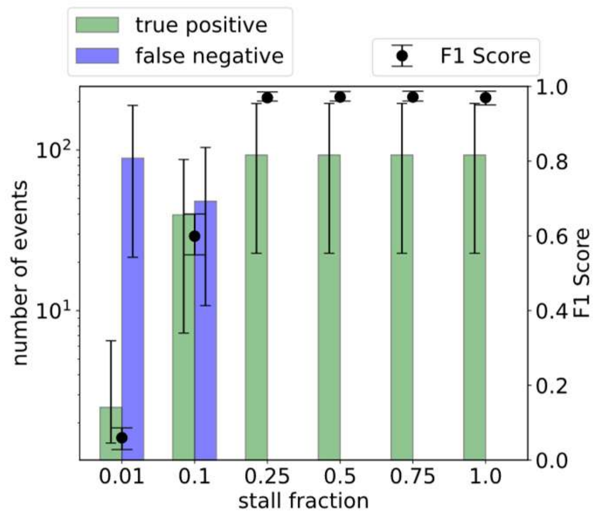
$$S = \frac{number\ of\ stuck\ rows}{total\ number\ of\ rows}$$



Result when run on dataset for Valdosta, Georgia, and S=1.



Result, averaged among all 38 locations, when S=1 and a day clearness threshold is implemented.



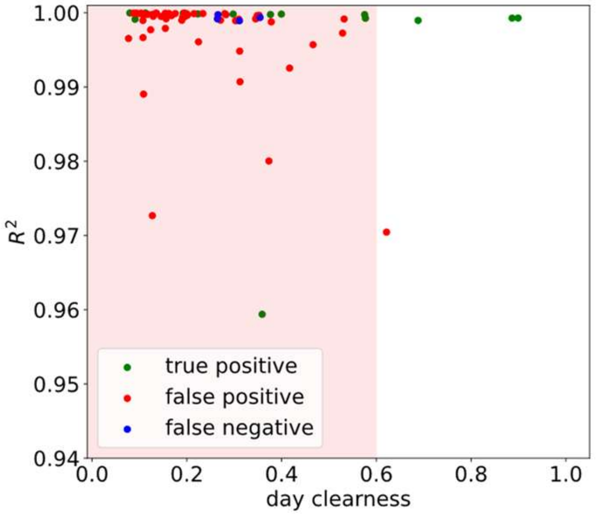
Result, averaged among all 38 locations, when a day clearness threshold of 0.6 is implemented, at varing S.

TAKEAWAY

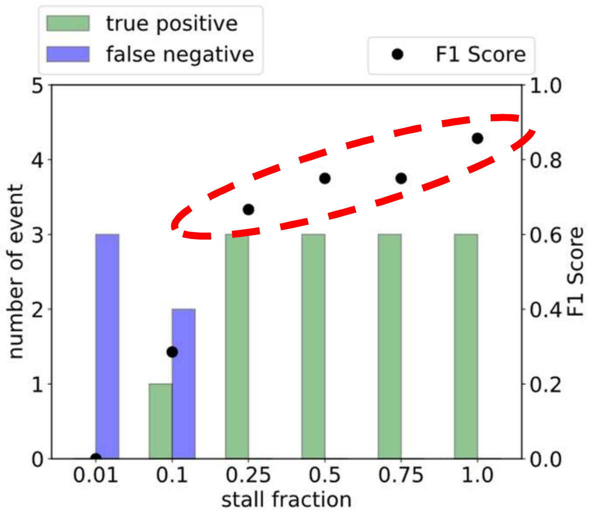
The algorithm is sensitive to day clearness, when day clearness is low the algorithm has low amount of data to make a classification. Implementing a day clearness threshold improves drastically the performance. 0.60 is found to be a good trade off between evaluated days and F_1 score, enabling a F_1=0.96. Partially stuck scenarios are easier to detect the higher is the stuck fraction. Scenarios with stuck fraction below 0.25 cannot be detected.

[3] DOI: 10.1016/j.renene.2023.04.035

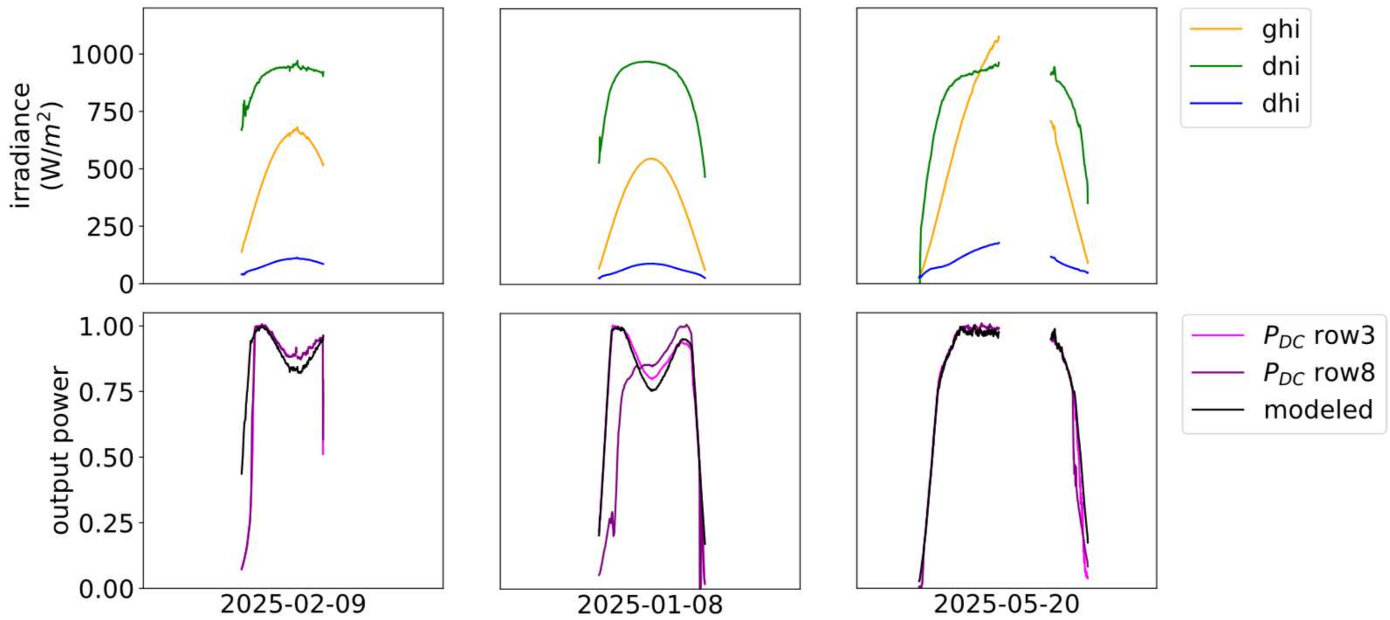
Validation of the algorithm on field data



Result when run on field dataset and S=1.



Result when run on field dataset and a day clearness threshold 0.6 is applied.



Days that make the algorithm reach a different F1 with different values of S.

TAKEAWAY

The algorithm is sensitive to cases in which underperformance is not related to weather conditions and appears to mimic a stuck condition. Although useful in some cases, January 8th and May 20th are not stuck events, thus are considered as FPs. Further claims per the field data are premature to make due to limited size of the data set (67 days with only 3 stalled events).

Conclusions

- Stuck events affects drastically the performance of PV arrays, up to 30% in cases where the tracker is stuck at 0°. Addressing their detection allows to avoid low energy performance.
- The detection algorithm's correctness is largely influenced by the day clearness: days with high day clearness are easier to classify.
- Implementing a day clearness threshold improves significantly the algorithm's performance. 0.60 looks like a sweet spot: improve the F1 from 0,60 to 0,96, and avoid removing the majority of days from the dataset.
- Partially stuck events can be detected with good performance if they are characterized by a stuck fraction above 0.25.
- The detection algorithm flags days when the underperformance is not related to weather conditions. For the aim of the algorithm these days are considered as FPs, but are days that should not be considered when addressing PV degradation analysis.

Future works

- Continue collecting field data to better address the performance in real conditions.
- Looking into more metrics that might improve the robustness of the algorithm.

Thanks for the attention!!

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