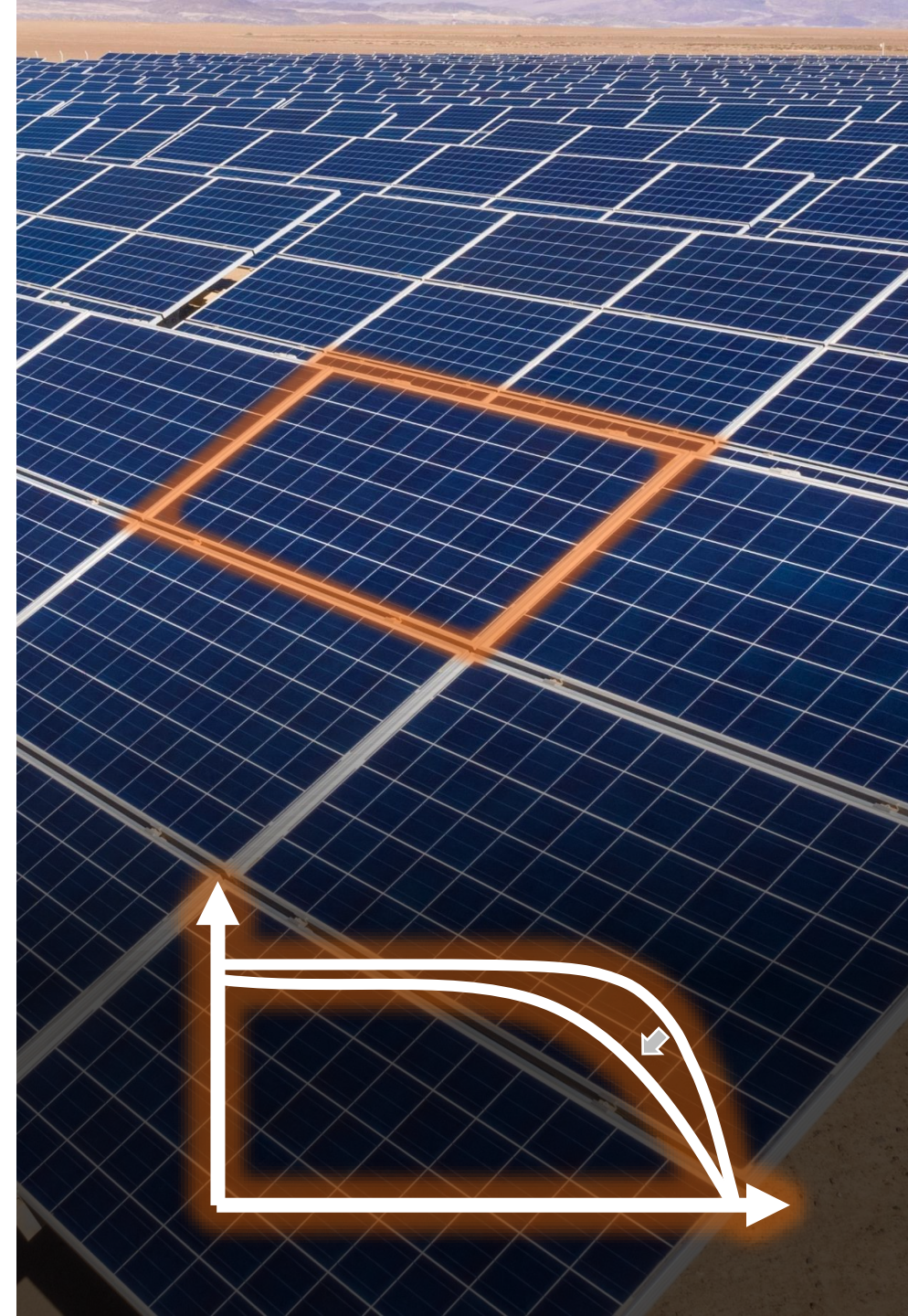


In-Situ Module IV Measurement

for PV System Performance
Monitoring & Control

Bill Stueve





Monitoring PV performance



What can we see by monitoring electrical performance at the inverter?

- Performance ratios
- Actual power produced
- Inverter operating current and voltage



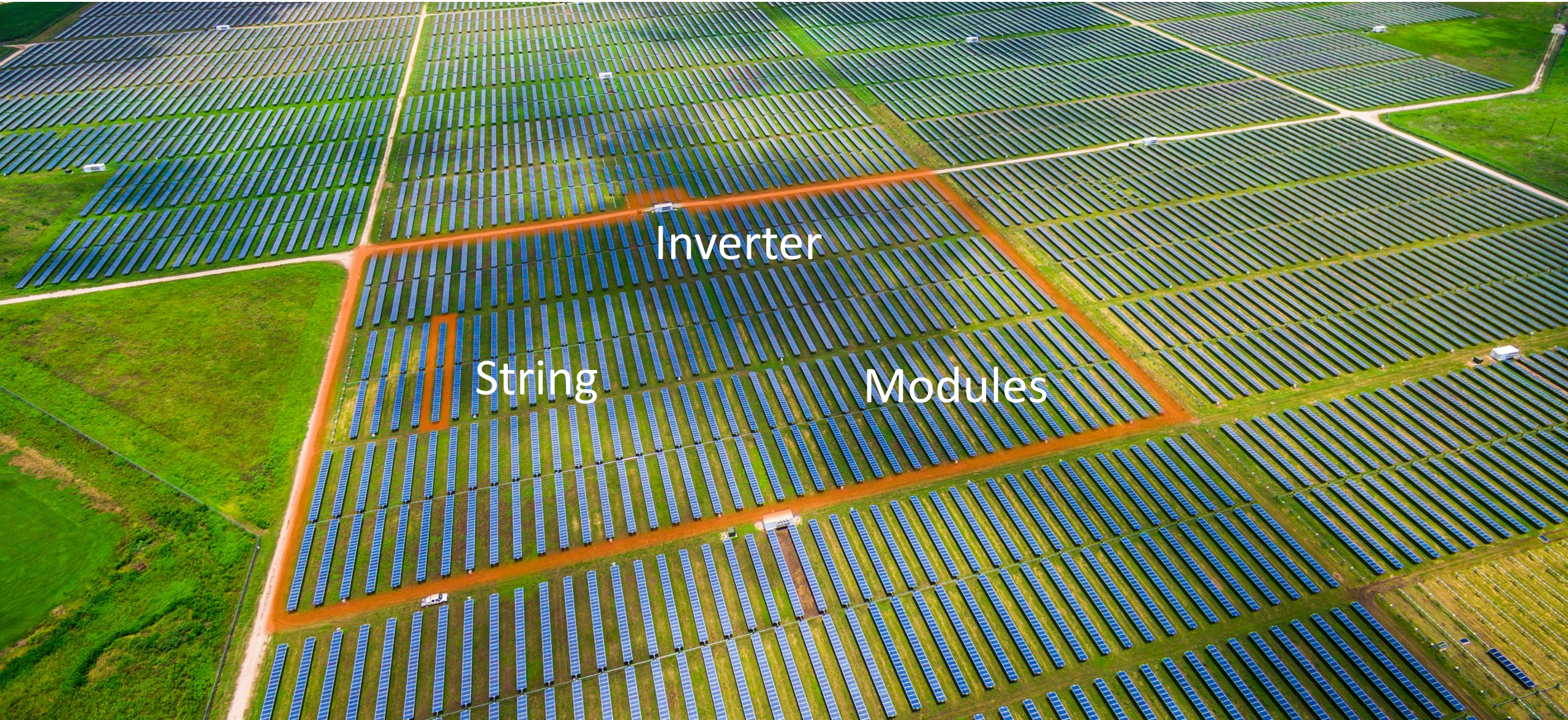
What do we **not** see by monitoring at the inverter?

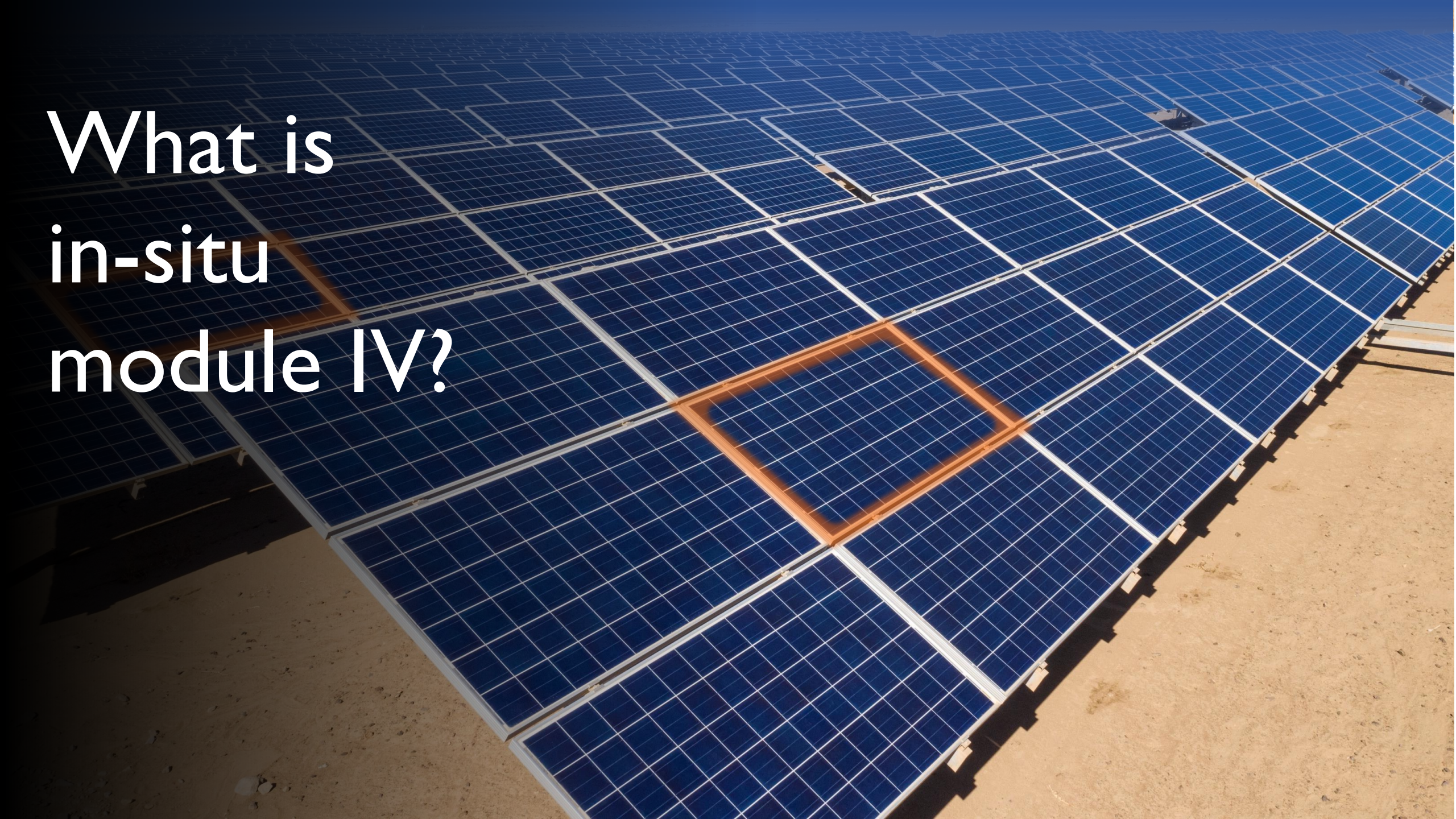
- Power losses hidden by clipping
- Potential power if not curtailed
- Soiling
- Module degradation
- Voltage loss
- Strings offline



Unlock information by measuring **within** the inverter block

More granular measurements

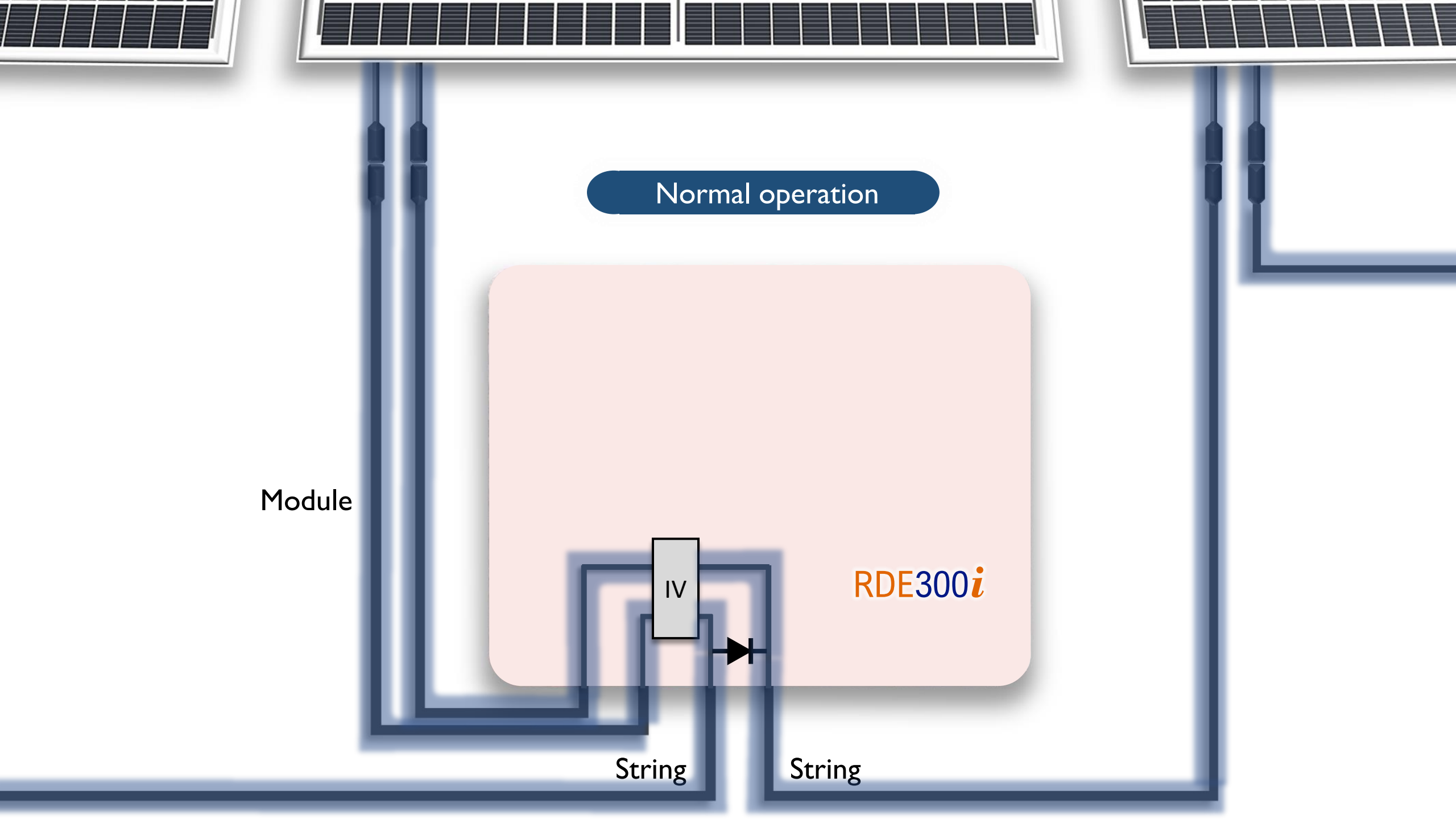




What is
in-situ
module IV?

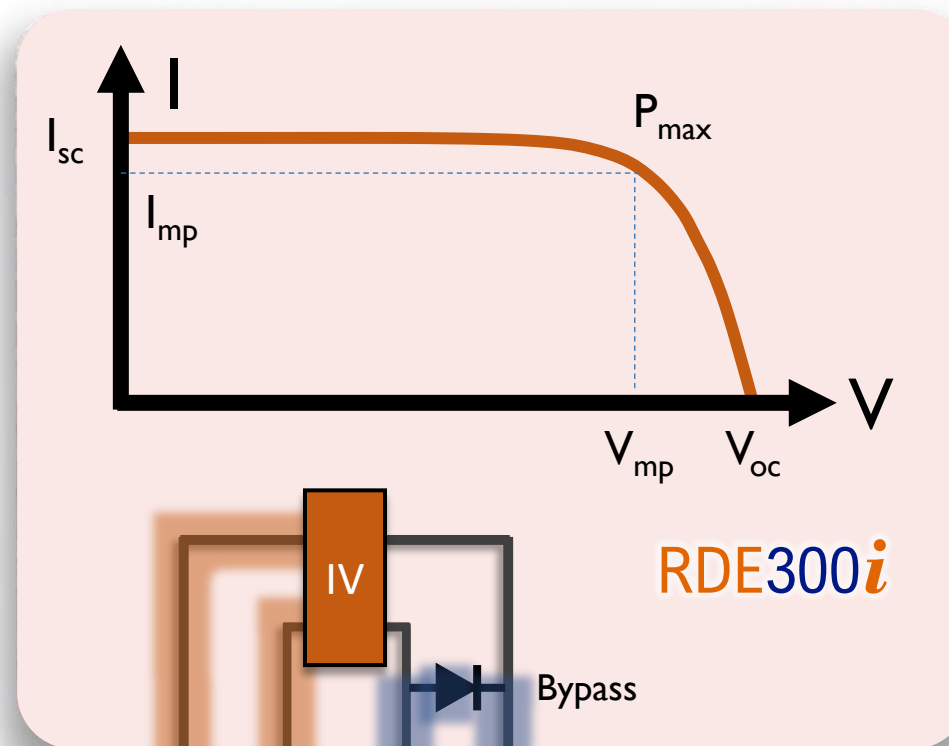
IV unit installed on module within string





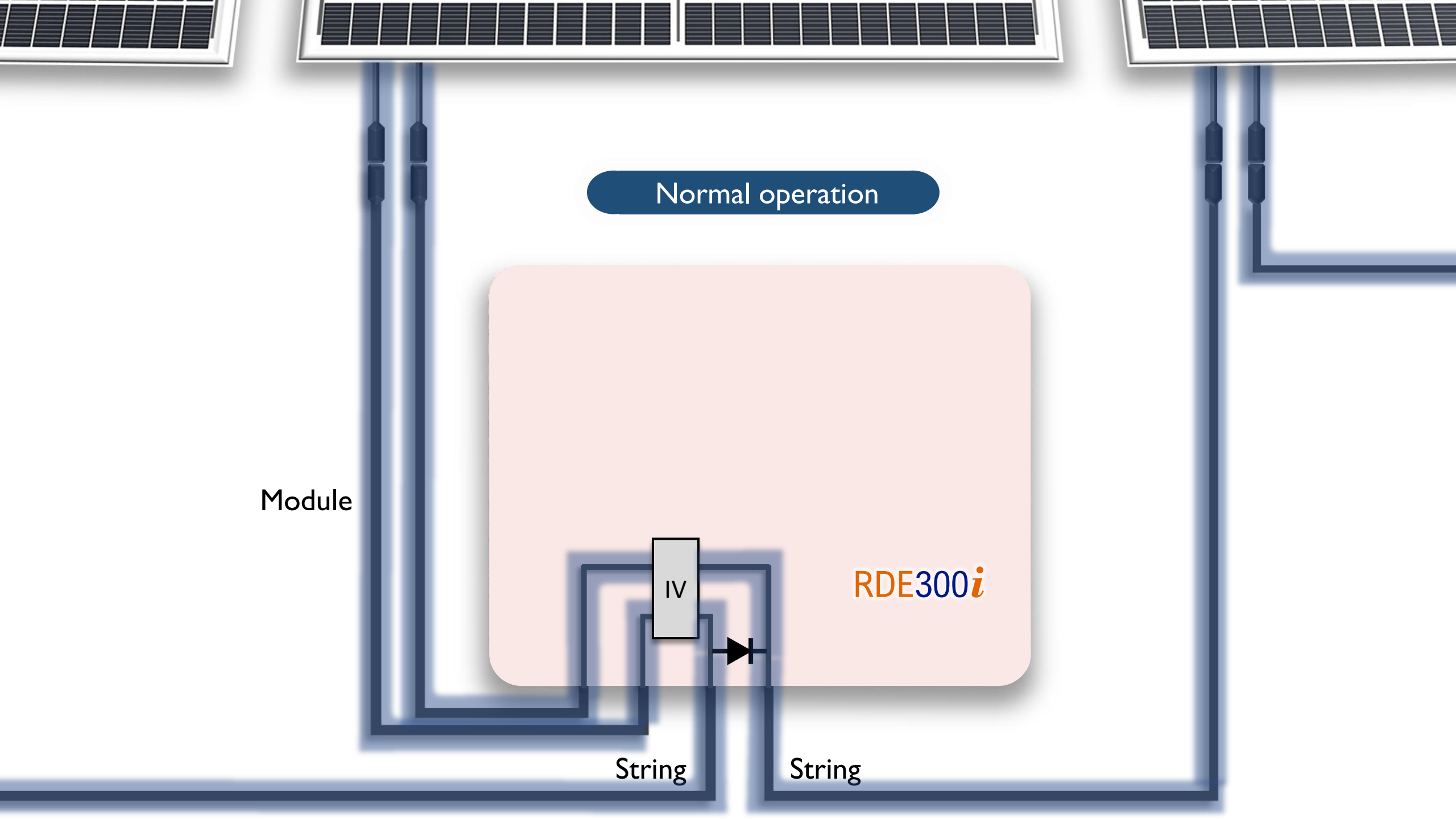
I-V Sweep

Module

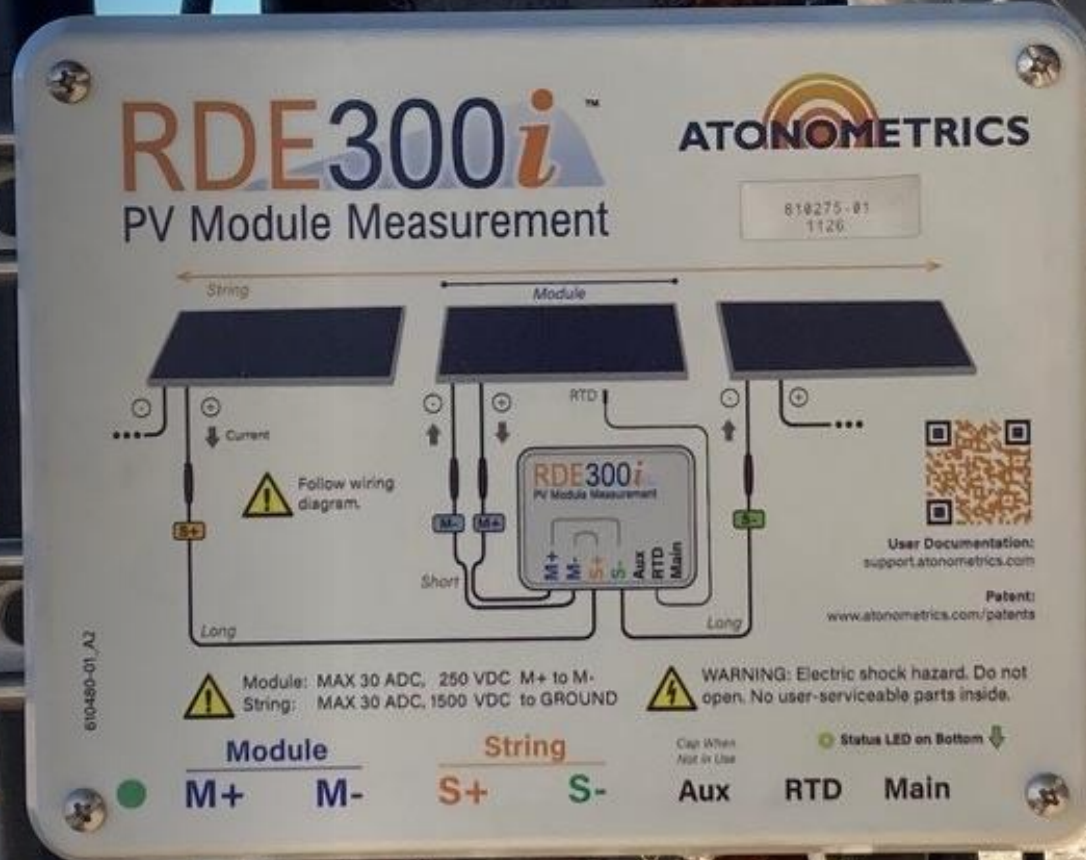


String

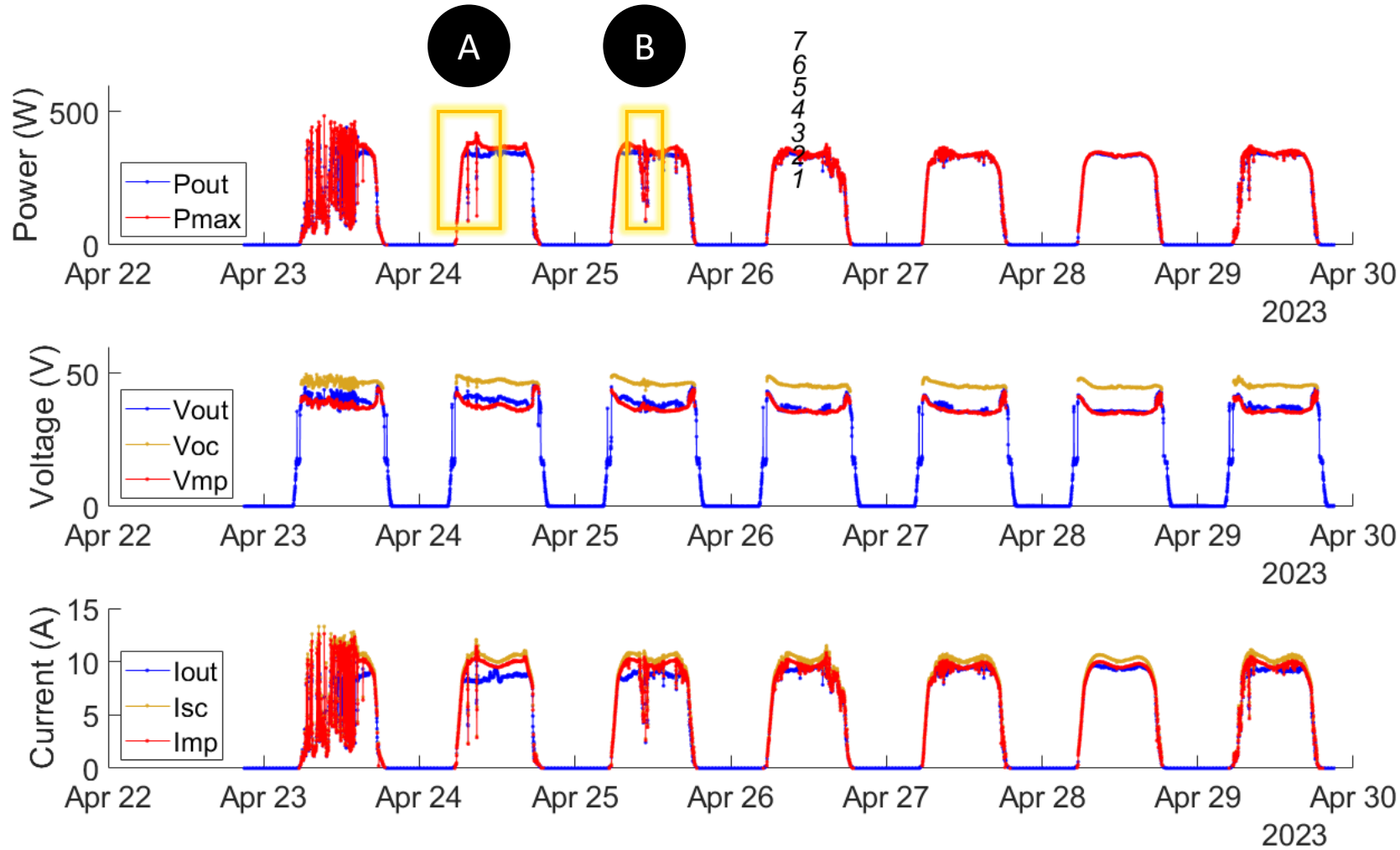
String



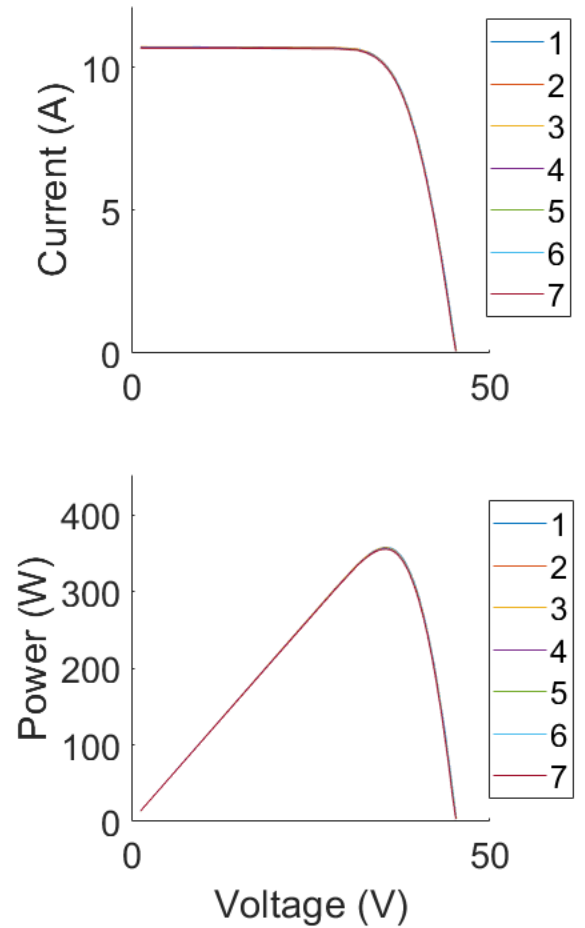
Example data



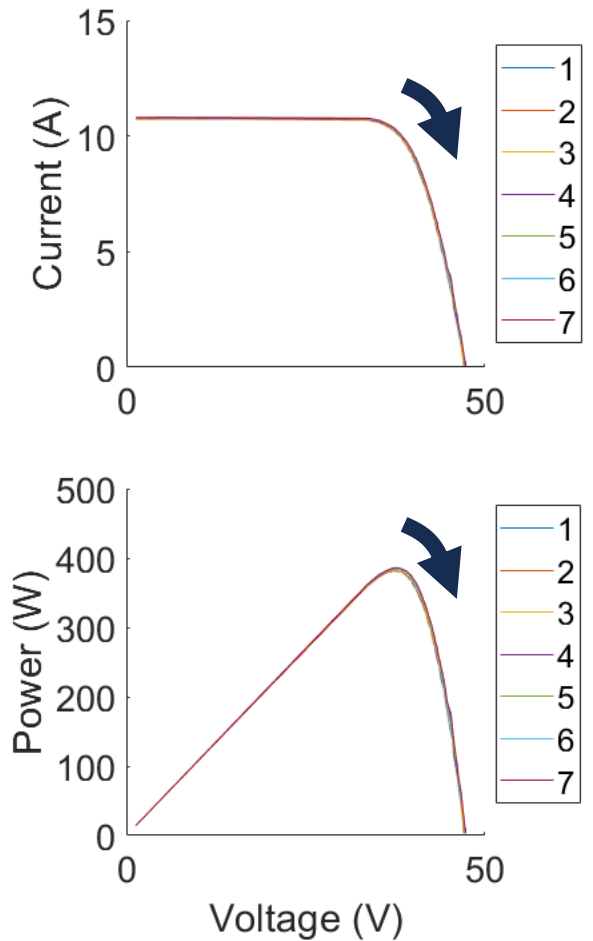
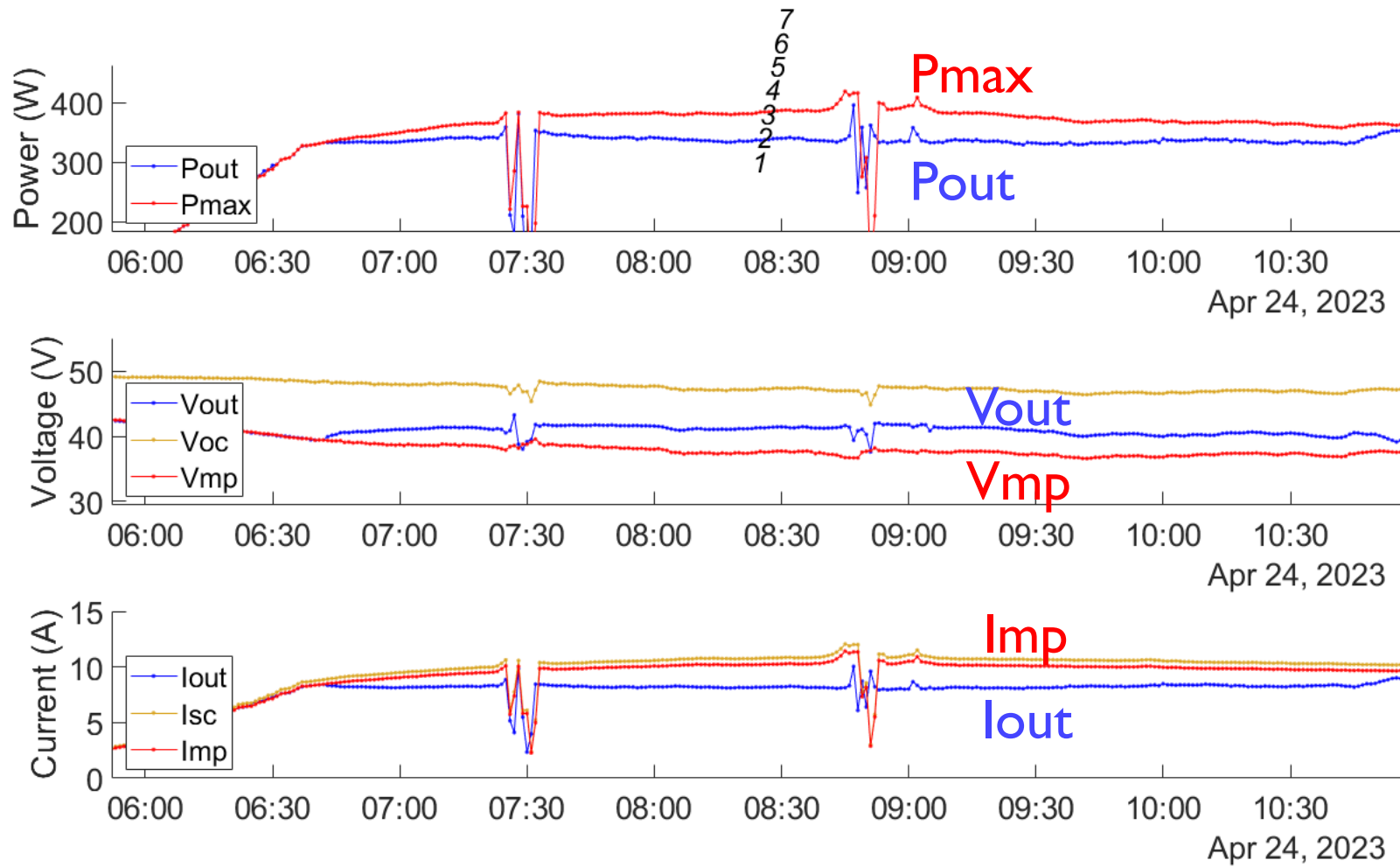
Module's available power, voltage, & current...vs. actual output to string



Real-Time I-V

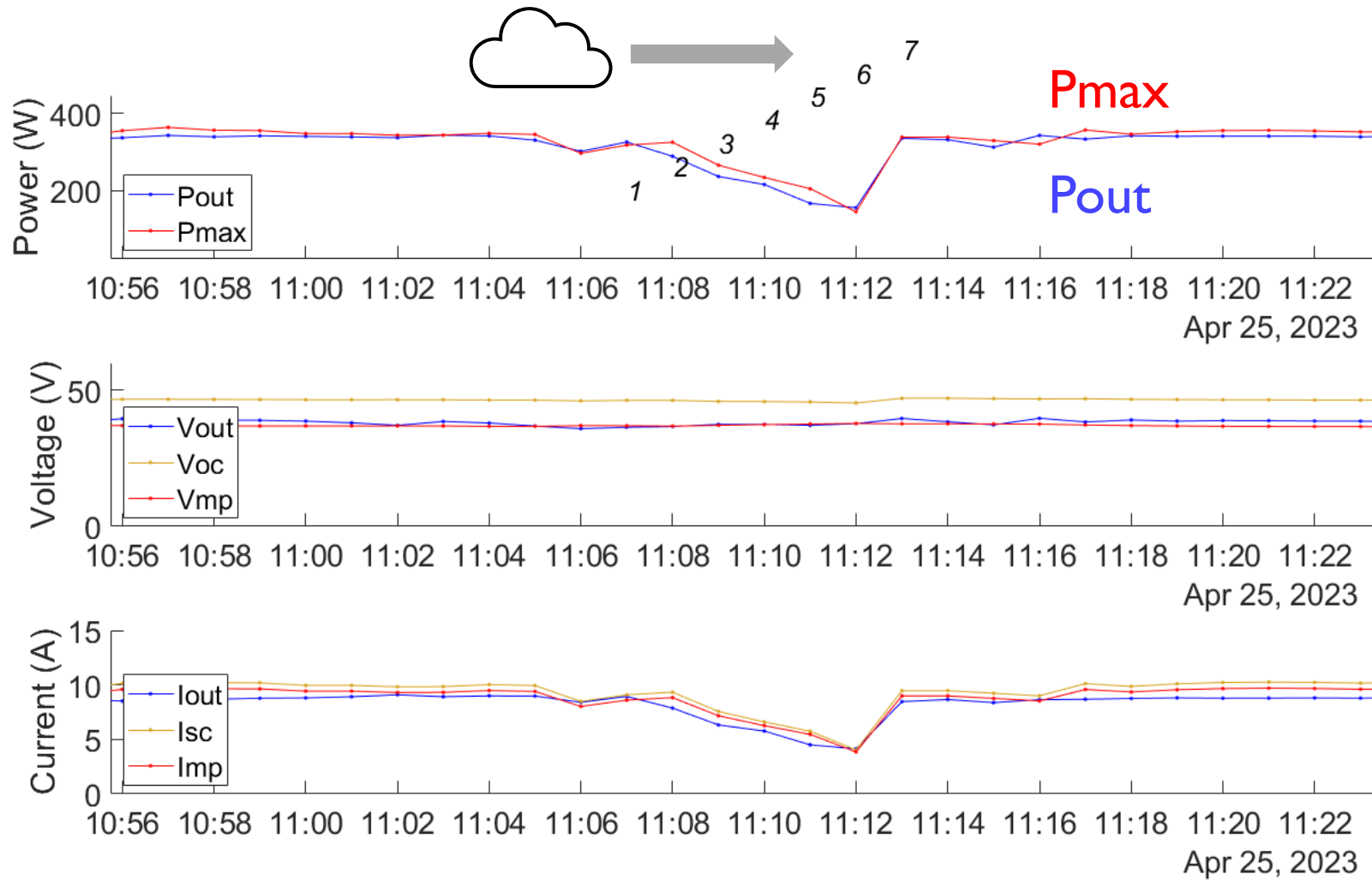


A Module available power exceeds inverter clipping limit

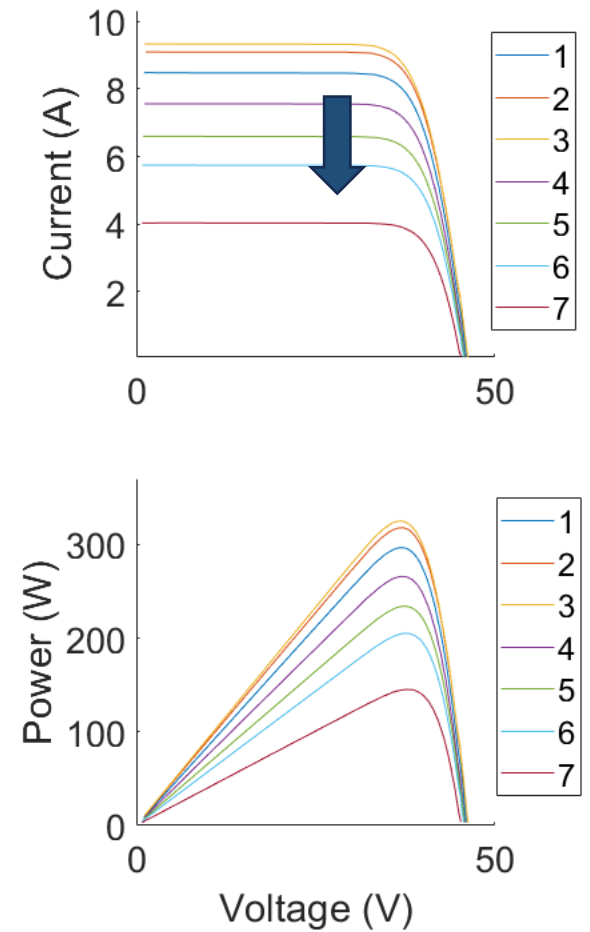


B

Power dips while cloud passes overhead



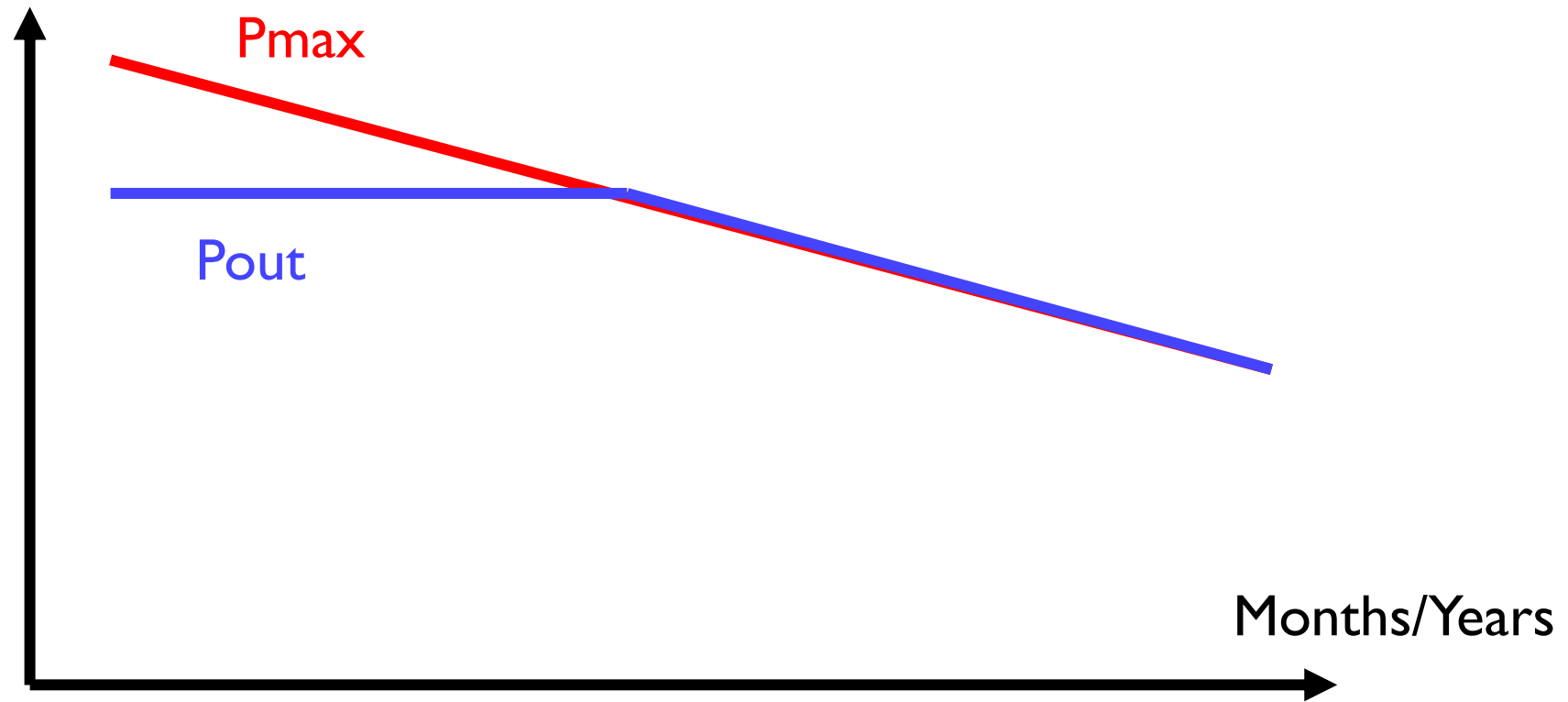
Real-Time I-V





Degradation losses

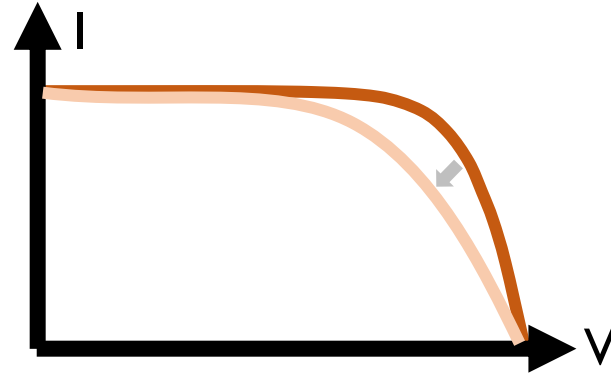
Detect module power loss that could be hidden by clipping



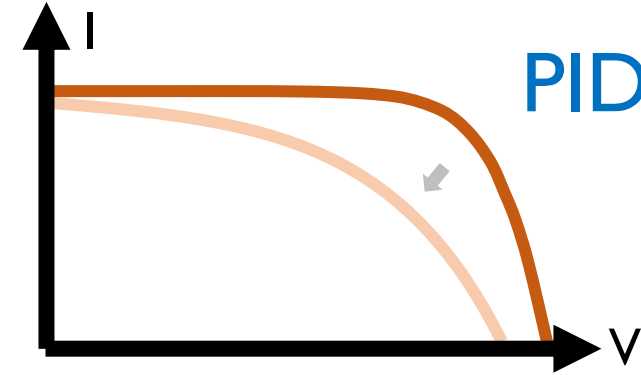
Earlier detection. No field or lab flash testing.

Observe module degradation modes by IV curve data

Cracks &
interconnect
damage

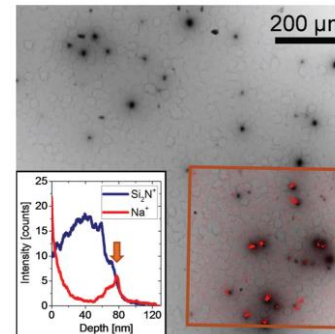
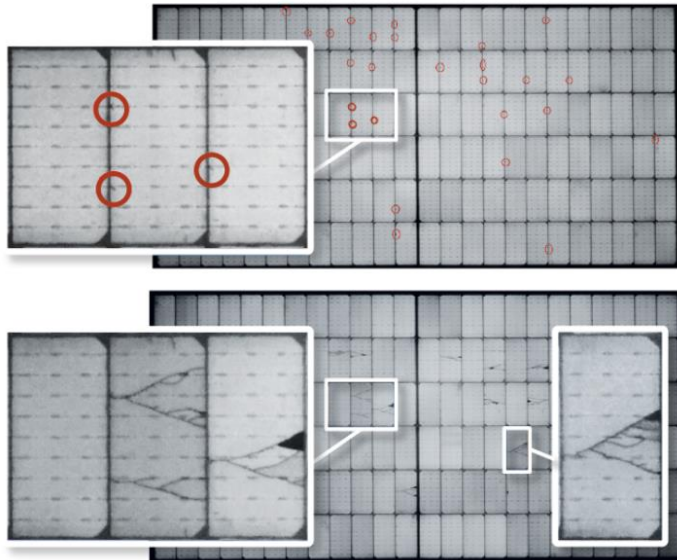


PID

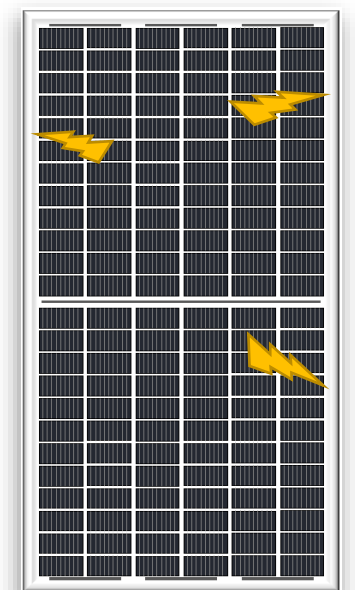
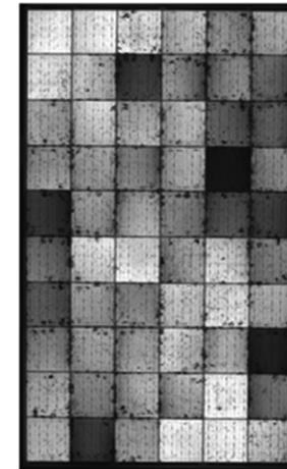


Bigger modules, bigger headaches?

APRIL 6, 2023 **pV magazine**



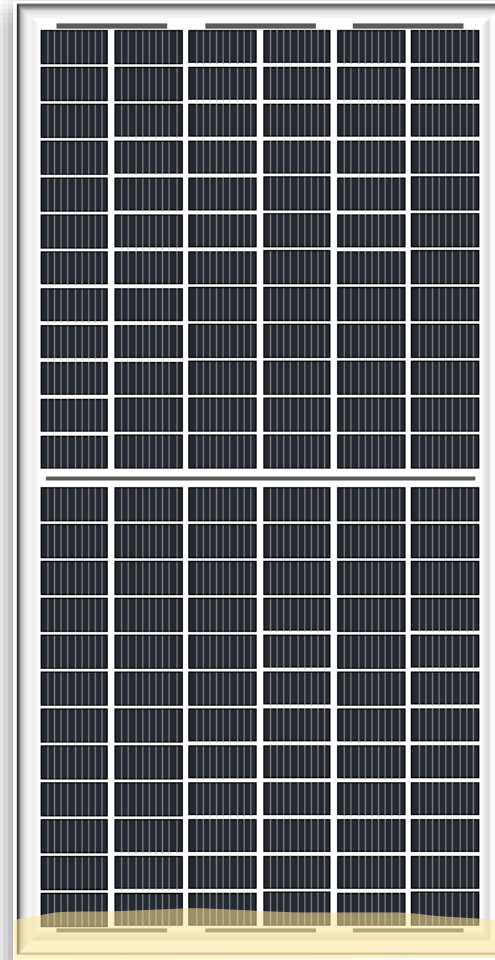
Luo et al, "Potential-induced degradation in photovoltaic modules: a critical review," Energy Environ. Sci., 2017





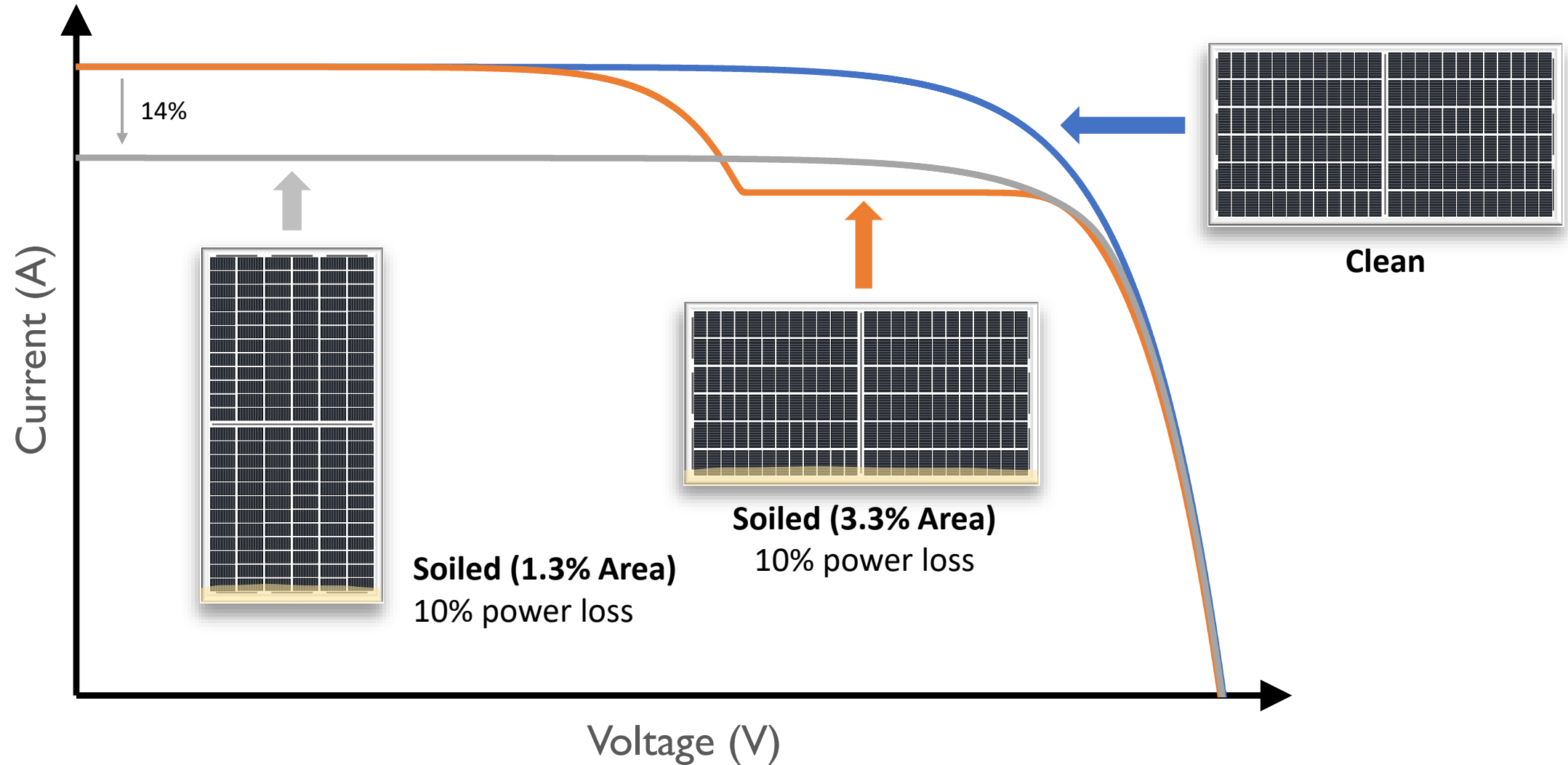
Soiling
losses

How much power is this module losing because of soiling?



Soiled
(1.3% of Active Area)

Non-uniform soiling causes disproportionate power loss

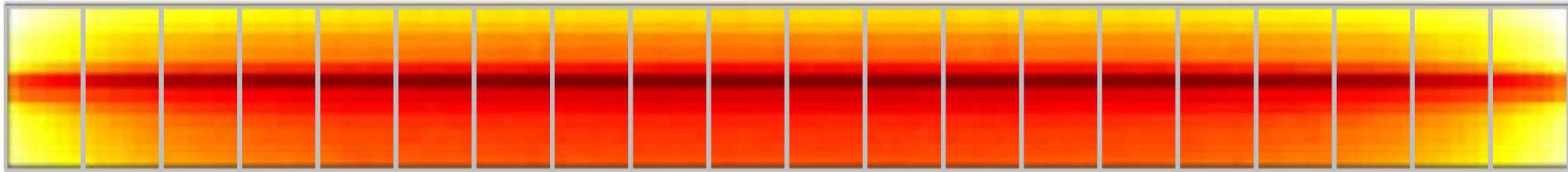






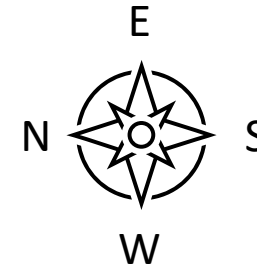
Bifacial irradiance

Summer, morning

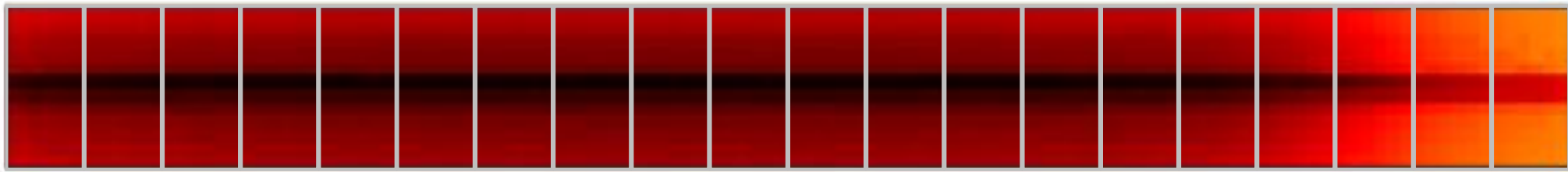


June 1st, 9 AM

**Rear-side irradiance is
highly non-uniform**



G_{rear}

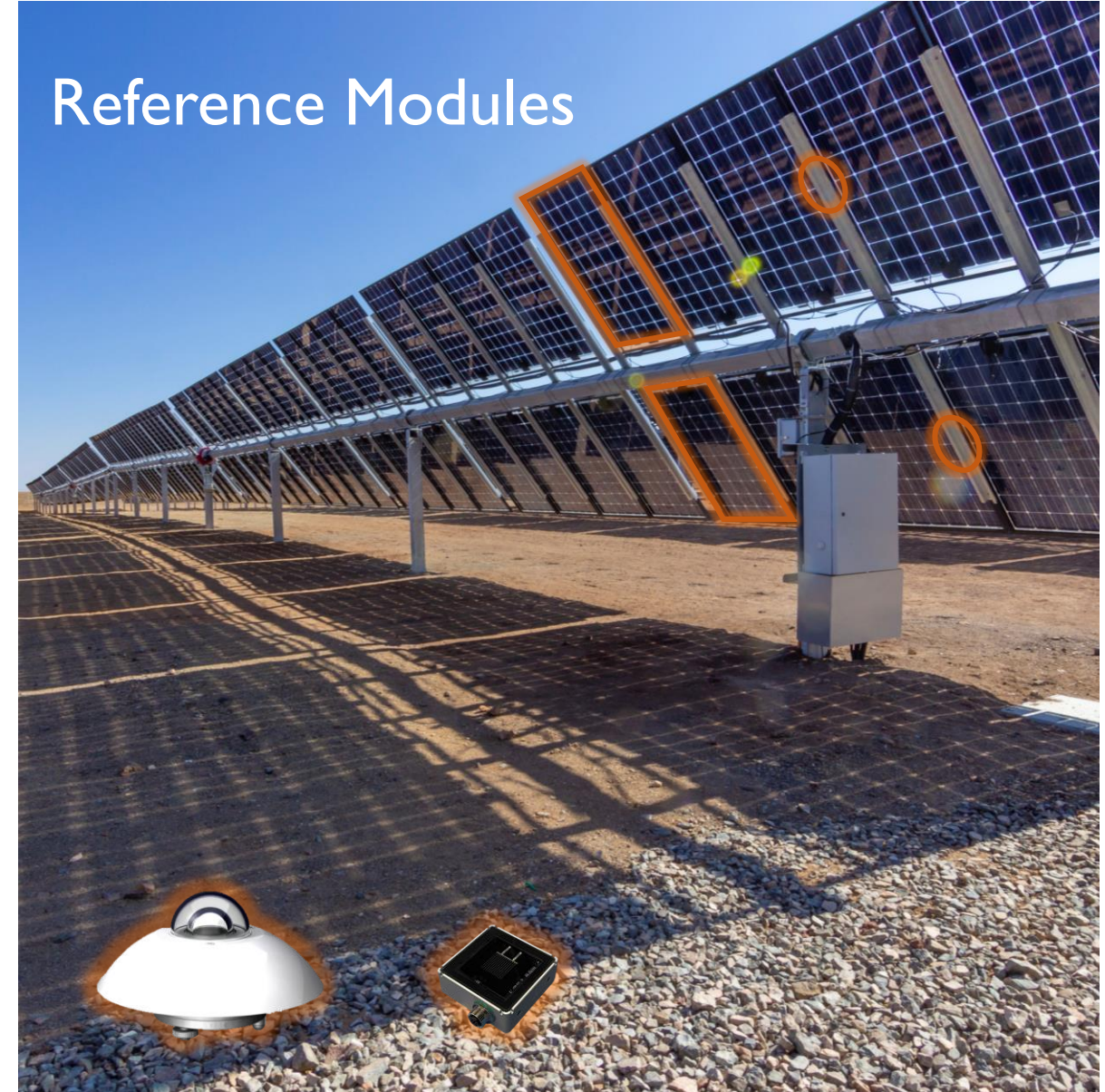


January 1st, noon

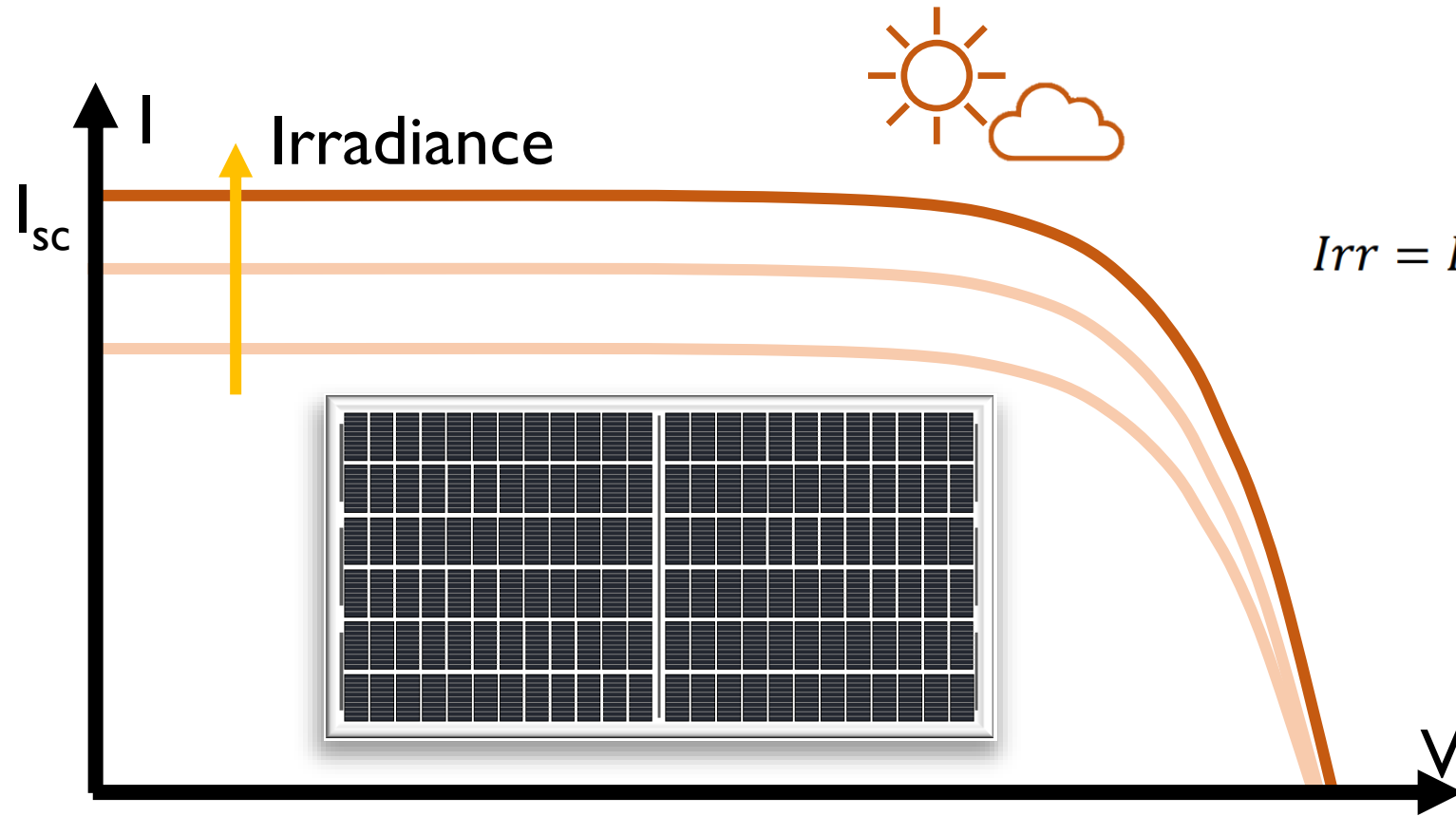
Winter, noon

100
90
80
70
60
50
40
30

Reference modules could simplify measuring total effective irradiance



Calibrated module I_{sc} yields total front plus rear irradiance...
Automatically accounts for albedo, spectrum, bifaciality, non-uniformity



$$Irr = Irr_{ref} \cdot \frac{I_{sc} \cdot (1 - \alpha \cdot (T - T_{ref}))}{I_{sc,ref}}$$



Real-time plant prediction

Future PV plants must support real-time 10-second forecasts of potential output while curtailed – to follow grid demand

PV plant providing grid ancillary services in Chile

Chile's National Electric Coordinator has granted approval for a new First Solar PV project to supply auxiliary grid services on a commercial basis. The installation has performed better than gas turbine technologies.

AUGUST 21, 2020 **PILAR SÁNCHEZ MOLINA**

GRIDS & INTEGRATION UTILITY SCALE PV CHILE



The Luz del Norte solar plant in Chile

Image: SMA / First Solar

Flow Power claims Australian first at new smart solar farm

Renewable energy retailer Flow Power claims that the integrated technology behind a new “smart” solar farm in the town of Berri, South Australia, is the first of its kind to be switched on in Australia.

APRIL 6, 2023 **DAVID CARROLL**

TECHNOLOGY AND R&D UTILITY SCALE PV AUSTRALIA



Demonstration of Essential Reliability Services by a 300-MW Solar Photovoltaic Power Plant

Clyde Loutan, Peter Klauer, Sirajul Chowdhury, and Stephen Hall
California Independent System Operator

Mahesh Morjaria, Vladimir Chadliev, Nick Milam, and Christopher Milan
First Solar

Vahan Gevorgian
National Renewable Energy Laboratory

Two groups challenge grid operator rules that restrict renewable energy

Earthjustice filed a complaint with FERC on behalf of SEIA that challenges a MISO rule that prohibits renewable energy resources from providing ancillary services.

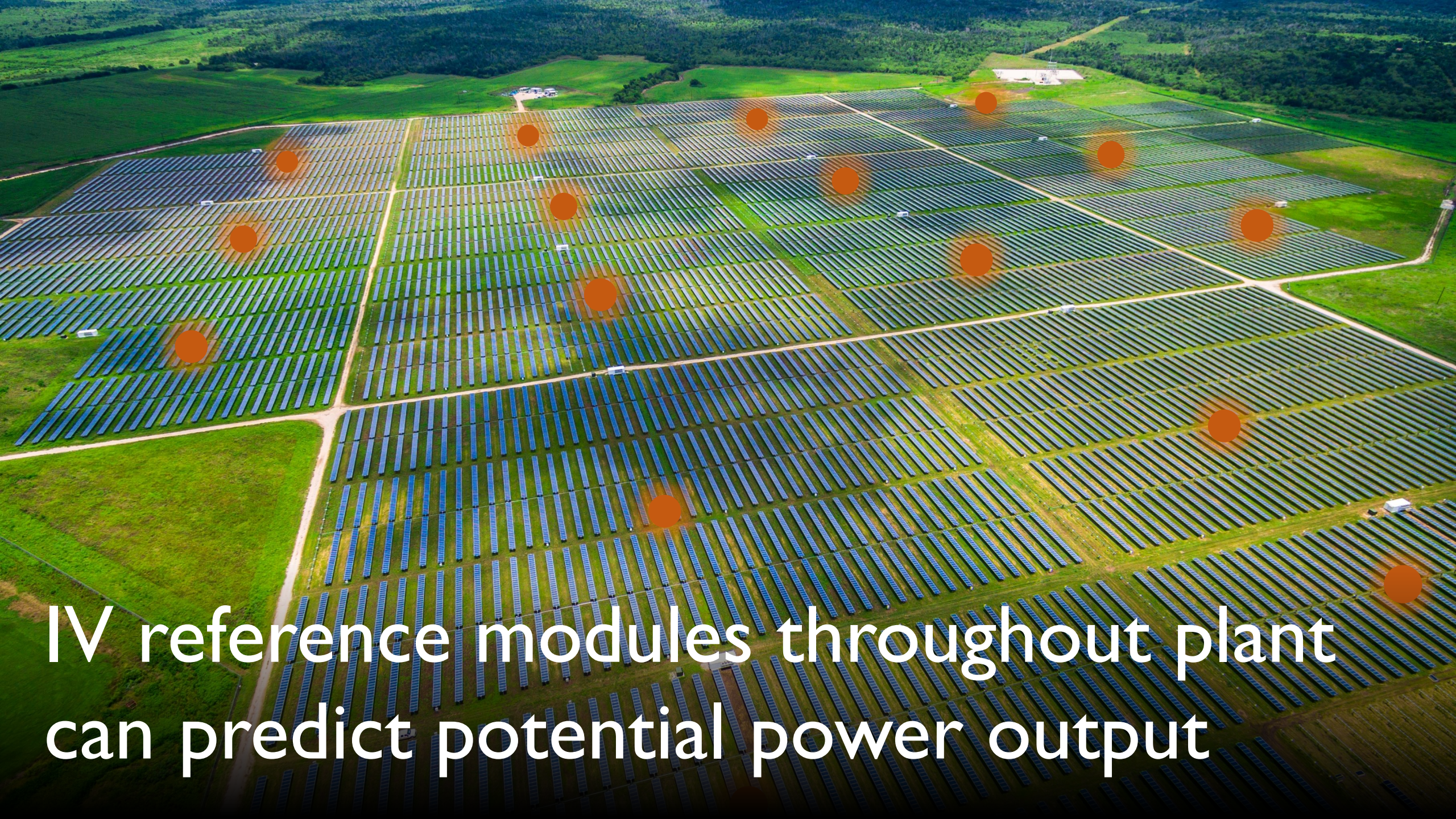
FEBRUARY 1, 2023 **ANNE FISCHER**

MARKETS MARKETS & POLICY POLICY UNITED STATES





What is the power availability 10 seconds from now?



IV reference modules throughout plant
can predict potential power output

Thanks

