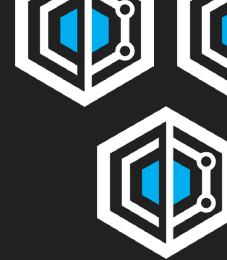


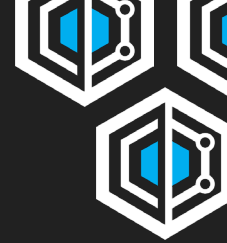


Performance Modeling of Operating Assets

(sorry no AI in this presentation)



A Journey Into the Underperformance Iceberg



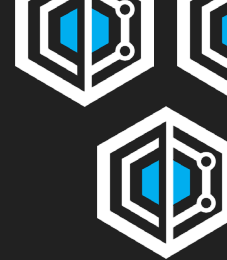
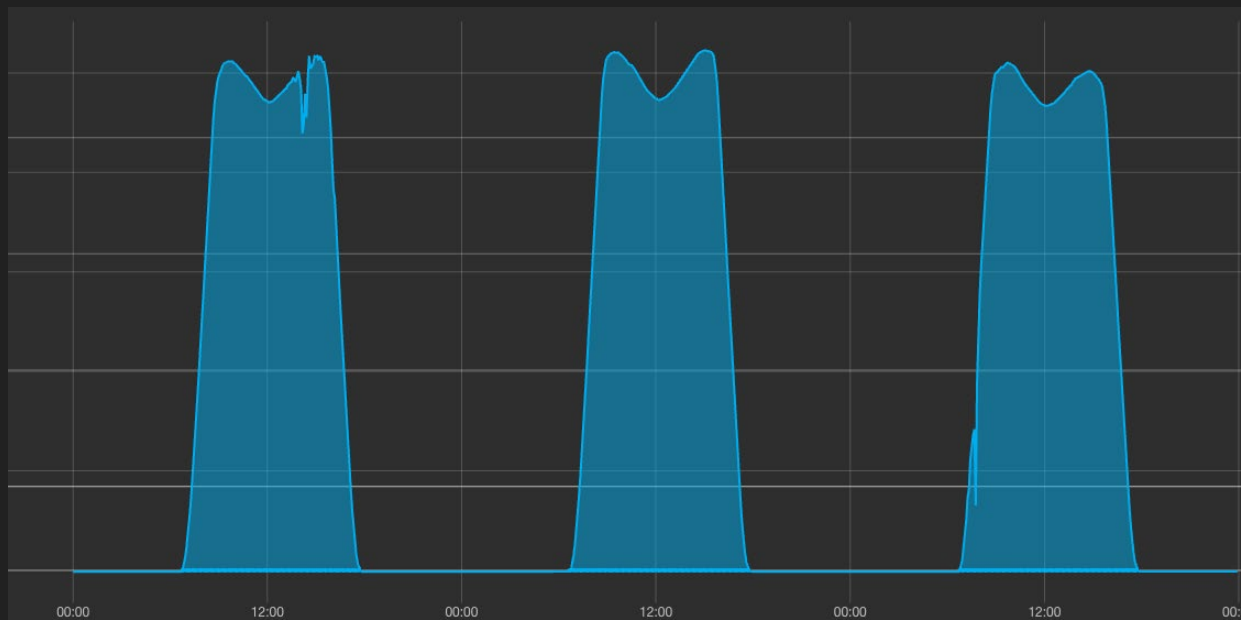
The Case Study

- A ~300 MWac project
 - 2 different tracker manufacturers
 - 2 different module families
 - 6 different module bins
 - 5 different met stations
 - DC line losses at a combiner differ from another combiner by up to 2%
- Caveat
 - Numbers in this presentation have purposely been obscured
 - Some X and Y axis labels have purposely been removed
 - Figures and maps have been taken from several different sources

Meter vs. Capacity

- Asset is 300 MWac
- It is Winter
- Peak output is ~259 MWac

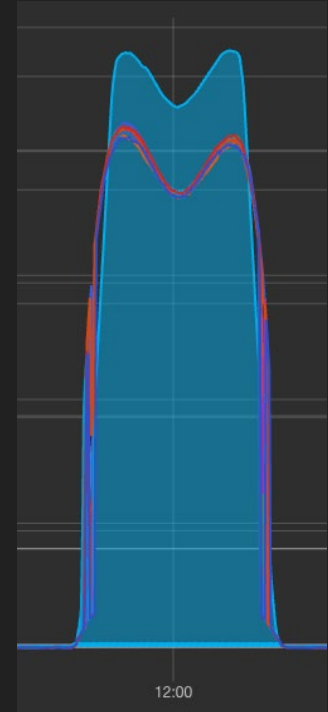
Power (kW)



Meter vs. Capacity

Rel. to POA

- Overview
 - Peak POA: $\sim 800 \text{ W/m}^2$
 - (80% of STC)
- DC
 - Plant DC Capacity: $\sim 402 \text{ MW}_{\text{dc}}$
 - Peak Output: $\sim 259 \text{ MW}_{\text{ac}}$
 - $\sim 64\%$ of peak capacity



Meter vs. Capacity

Rel. to POA

The Surface
(You could do this in Excel)



Meter vs. Capacity

Rel. to POA

Meter Performance Index

- Asset is underperforming
 - ~15%

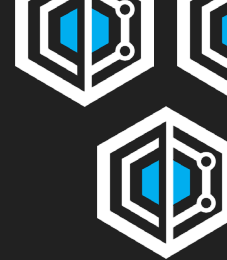


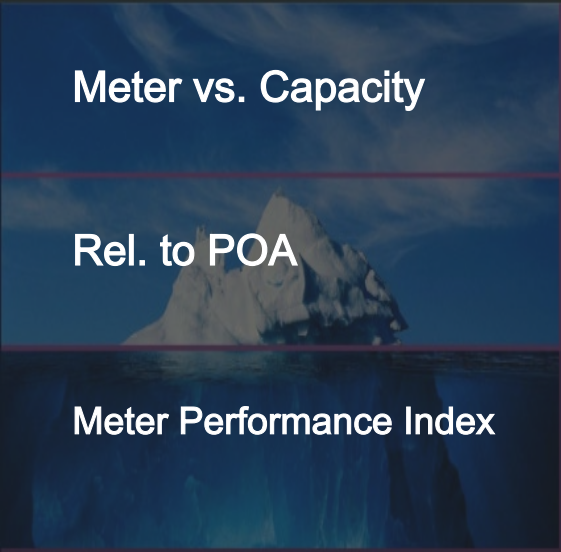
Meter vs. Capacity

Rel. to POA

Meter Performance Index

- Could also use:
 - Performance Ratio
 - Temperature Corrected Performance Ratio
 - Regression Model
 - ML Model



An iceberg floating in the ocean. The tip of the iceberg is above the water line, and the much larger base is submerged. Two horizontal red lines divide the image into three sections. The top section (above the water) is labeled 'Meter vs. Capacity'. The middle section (at the water line) is labeled 'Rel. to POA'. The bottom section (submerged) is labeled 'Meter Performance Index'. To the right of the iceberg, two large curly braces group the top two sections under the heading 'The Surface' and the bottom section under the heading 'Ratio -Pelagic Zone'.

Meter vs. Capacity

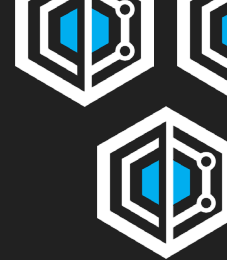
Rel. to POA

Meter Performance Index

The Surface

Ratio -Pelagic Zone

(You probably want a performance engineer with specialized tools)



Meter vs. Capacity

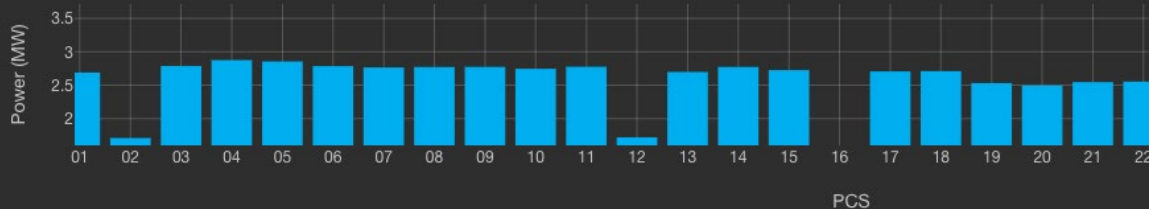
Rel. to POA

Meter Performance Index

Inverter Comparison

- All inverters on Day 1
 - Some inverters clearly underperforming
 - What about 19?

PCS Output Distribution



Meter vs. Capacity

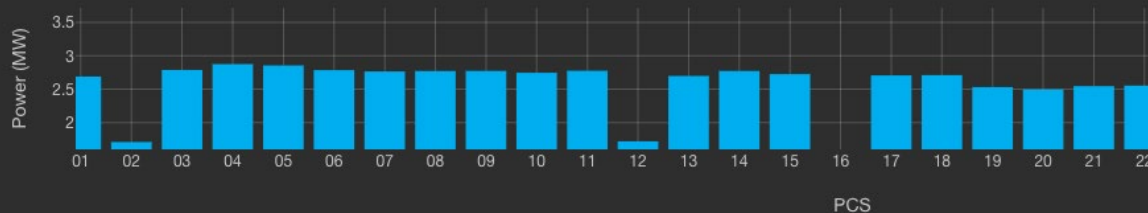
Rel. to POA

Meter Performance Index

Inverter Comparison

- When normalized to installed capacity, seems okay
- 3 underperforming inverters out of ~100 doesn't explain 15% underperformance

PCS Output Distribution



PCS Output Distribution

☒ Normalize by DC Input



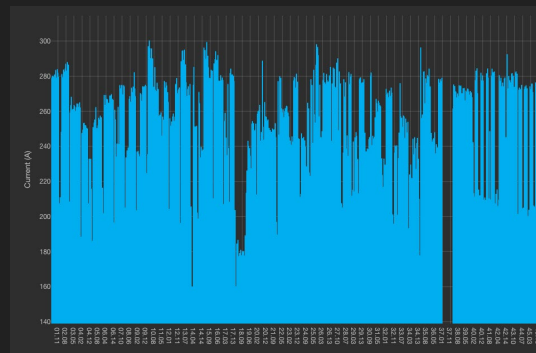
Meter vs. Capacity

Rel. to POA

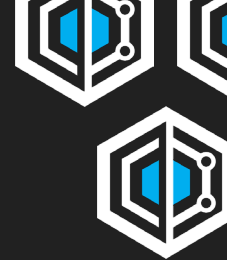
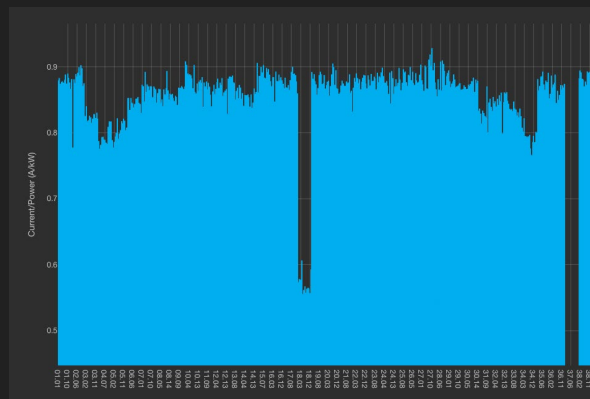
Meter Performance Index

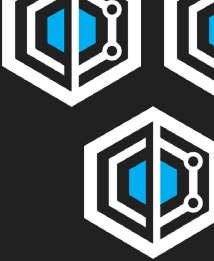
Inverter Comparison

Combiner Comparison



Normalize by
DC Capacity





Meter vs. Capacity

Rel. to POA

Meter Performance Index

Inverter Comparison

Combiner Comparison

The Surface

Ratio -Pelagic Zone

Meso -Relativity Zone
(Engineers and AI tools live here)

Meter vs. Capacity

Rel. to POA

Meter Performance Index

Inverter Comparison

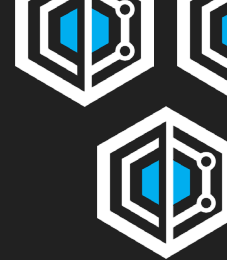
Combiner Comparison

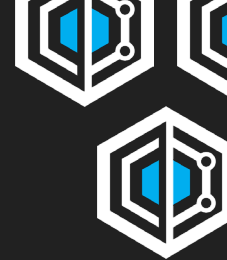
Device Performance
Index

Ratio -Pelagic Zone

Meso -Relativity Zone

Abyssso -Modeling Zone





Yet Another Performance Model

Why?



Sub
minute

Geo
spatial

1000s
of DC
Fields

Irreg.
Interval

Many
Met
station

Data
Filters

Stream
ing

100's
Simul.
project

SCADA

- Lots of streaming data
- Lots of bad data

Timestamp	Device	Value
8:01:07	Sensor A	7.3
8:01:09	Sensor A	8.3
8:02:33	Sensor B	100.78
8:05:47	Soiling Sensor	197% Soiled

- Satellite Data



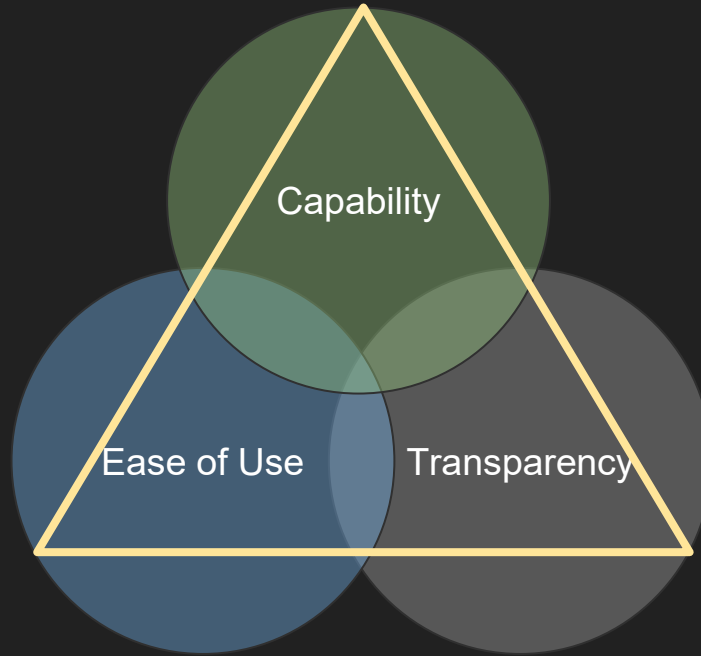
*Fictitious Data

- Lots of streaming data
- Lots of bad data
- Coming from many met stations
- With lots of devices reporting data back to us



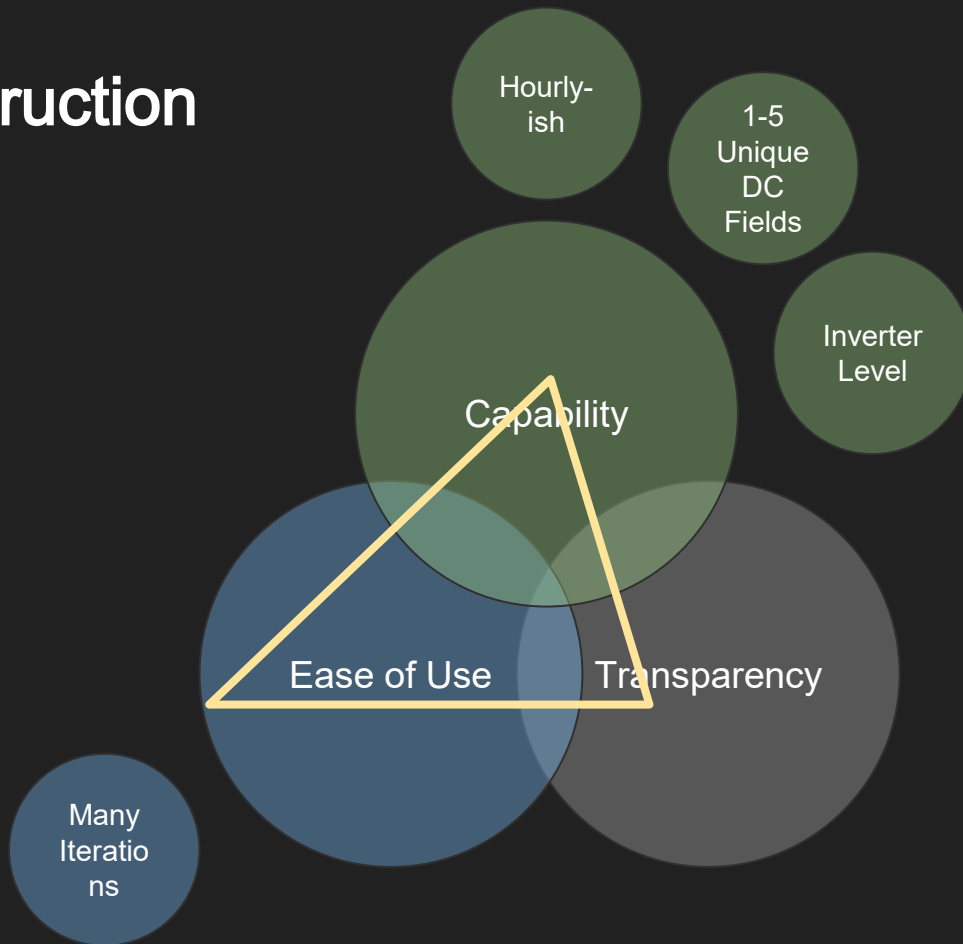


The Ideal Performance Model

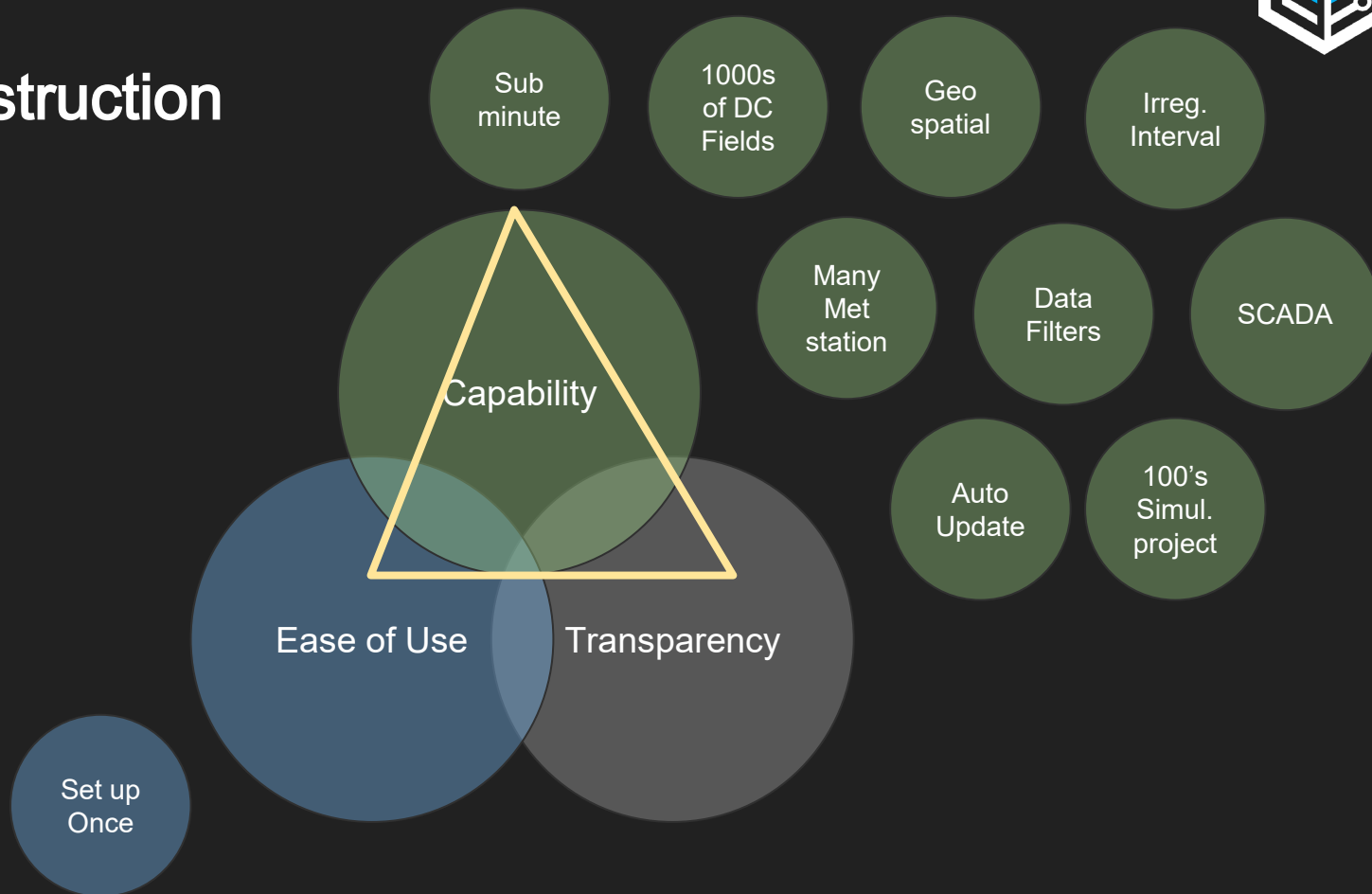




Pre-construction



Post - construction



Sub
minute

Geo
spatial

1000s
of DC
Fields

Irreg.
Interval

Many
Met
station

Data
Filters

Auto
Update

100's
Simul.
project

SCADA

~3000 Combiners

~600 MW project



5 Minute Intervals

(12x more time stamps
than standard pre-
construction models)



36,000 performance model runs

(lots of computer memory)
(lots of time)

Sub
minute

Geo
spatial

1000s
of DC
Fields

Irreg.
Interval

Many
Met
station

Data
Filters

Auto
Update

100's
Simul.
project

SCADA

Programming
Language
Speed

C / Rust

Java

Python

Vectorization

Multiprocessing

SIMD

Programming Tricks / Algorithms

Sub
minute

Geo
spatial

1000s
of DC
Fields

Irreg.
Interval

Many
Met
station

Data
Filters

Auto
Update

100's
Simul.
project

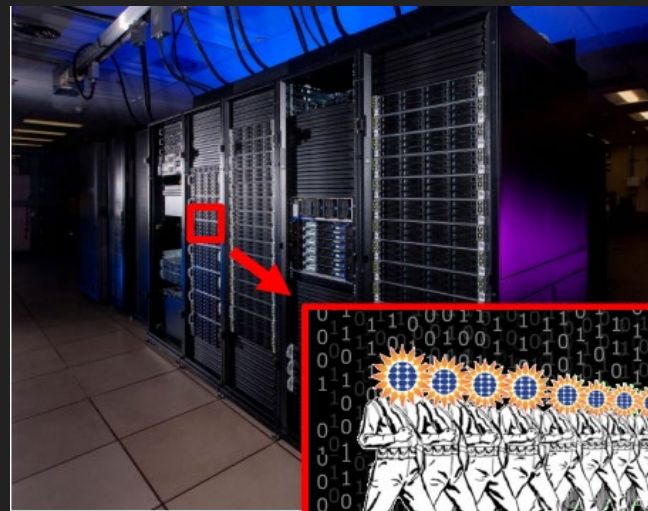
SCADA

Bigger
Machines

Laptop

Server

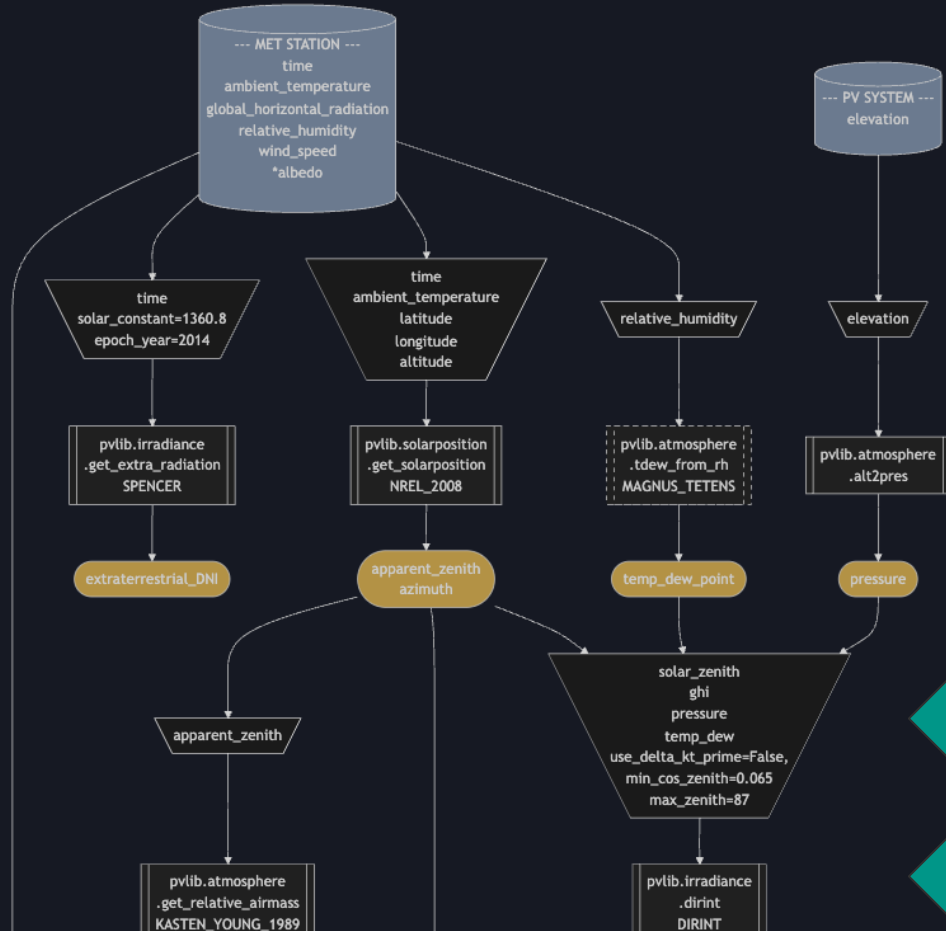
Cloud



Kevin Anderson
PV Atlas PVPMC
2024



Model Chain



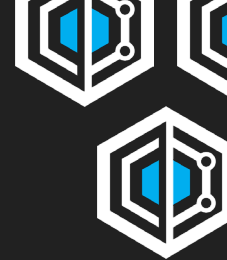
- Custom Model Chain

- Wrap each important function with a compress/decompress cycle
- docs.proximal.energy

Compress

PVLIB

Decompress



Yet Another Performance Model

So what?



Sub
minute

Geo
spatial

1000s
of DC
Fields

Irreg.
Interval

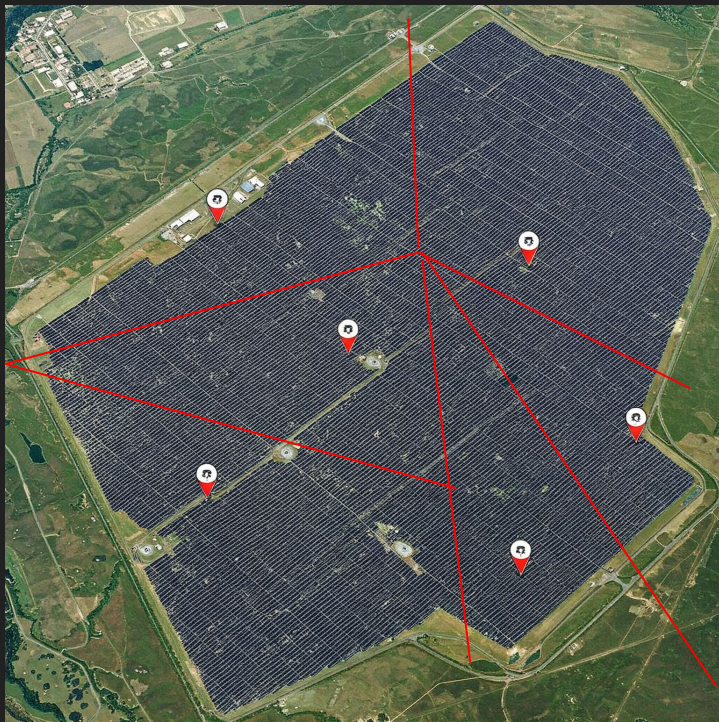
Many
Met
station

Data
Filters

Auto
Update

100's
Simul.
project

SCADA



- Individual performance index calculations per device, with associated met data
- (I am not good at drawing voronoi diagrams)

*Fictitious Data

Sub
minute

Geo
spatial

1000s
of DC
Fields

Irreg.
Interval

Many
Met
station

Data
Filters

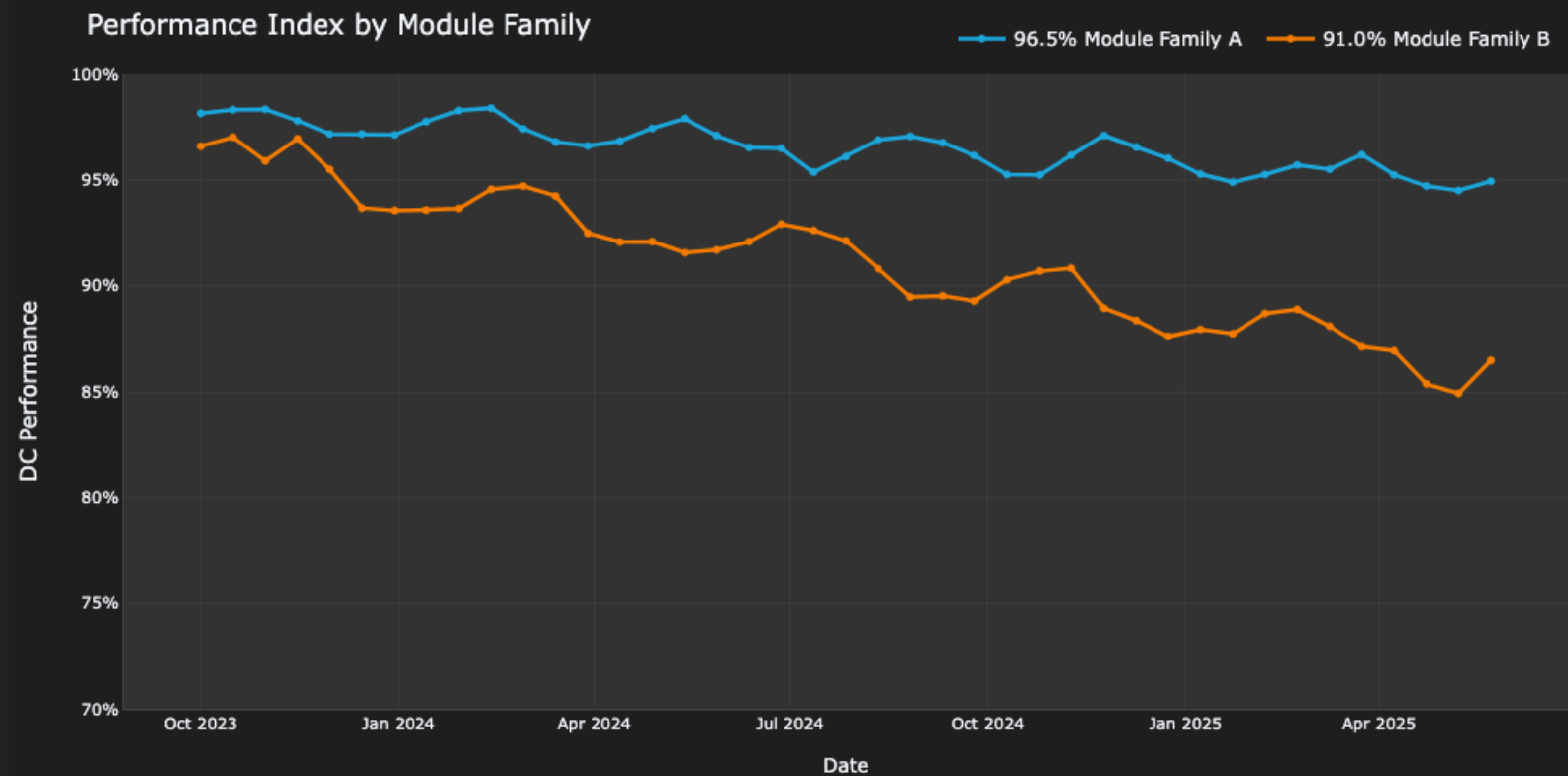
Auto
Update

100's
Simul.
project

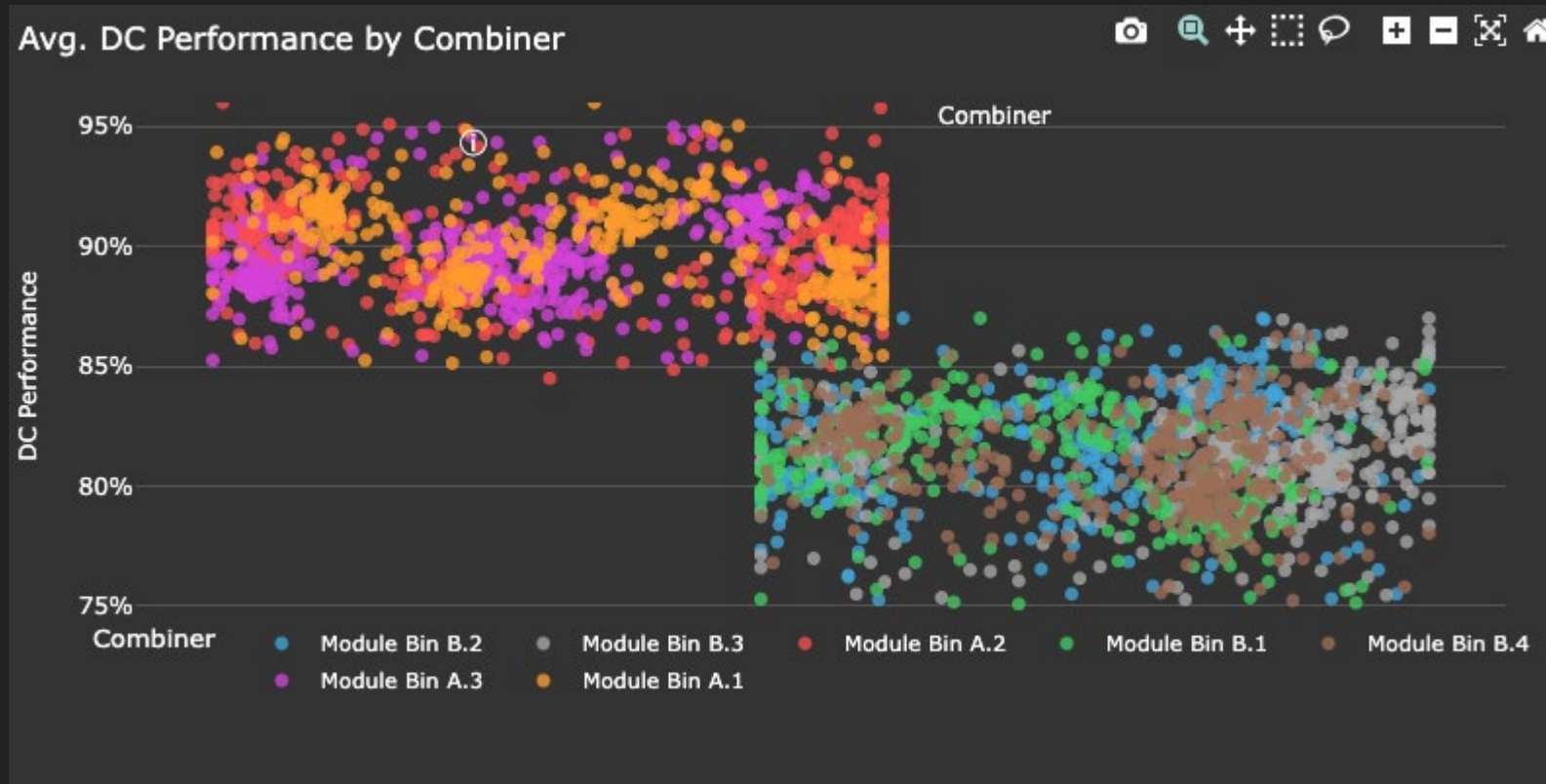
SCADA



*Fictitious Data



*Fictitious Data



Thank you!

<https://kurt-rhee.gitbook.io/blog/writings/pv/modeling-operating-pv-assets>

