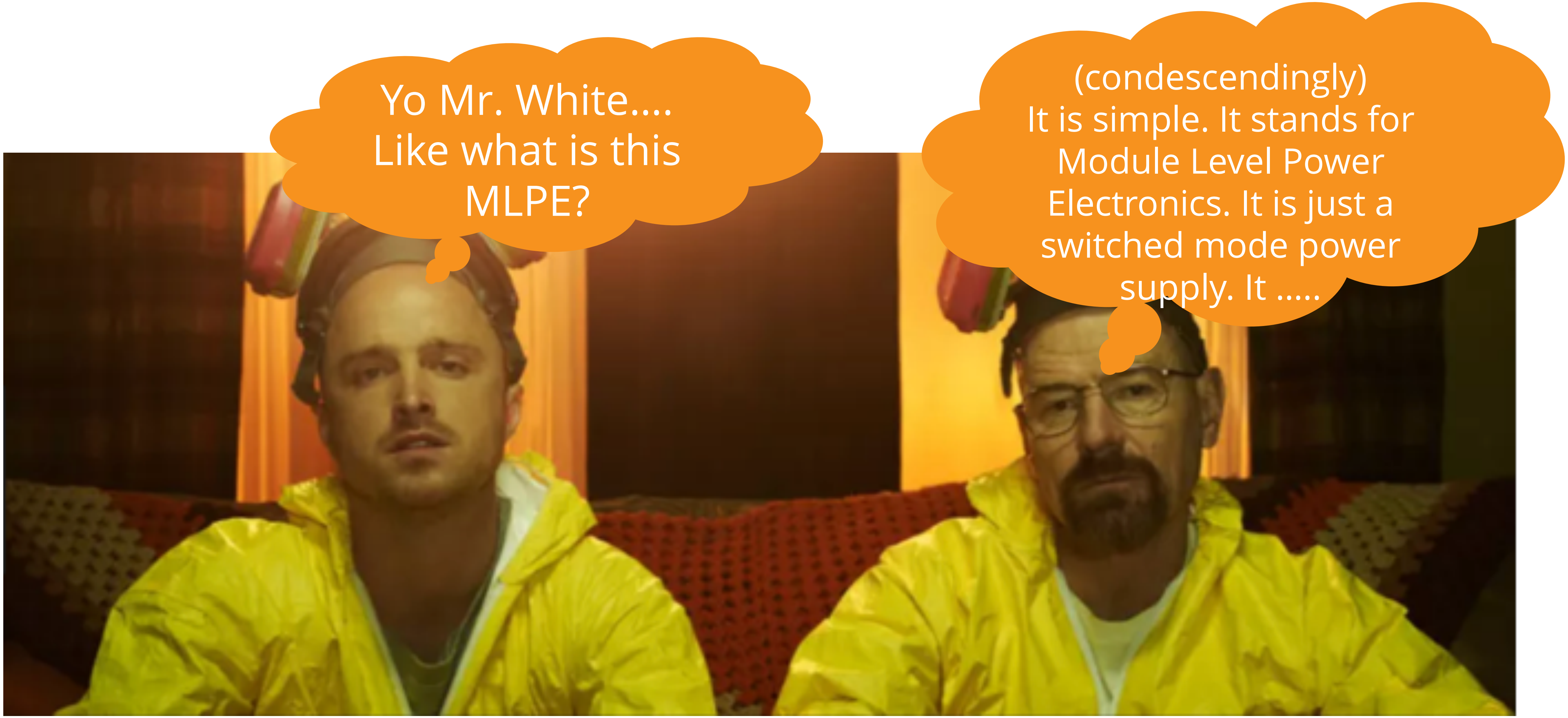
MLPE Performance modeling
Module Level Power Electronics

Chetan Chaudhari, Tamir Lance, Gregory M. Kimball, Ben Bourne | May 2019

12th PV Performance Modeling and Monitoring Workshop (May 14-15, 2019)


Yo Mr. White….
Like what is this
MLPE?
(condescendingly)
It is simple. It stands for
Module Level Power
Electronics. It is just a
switched mode power
supply. It …..

MLPE - Module Level Power Electronics

- Key benefits
  - Balance Of System component for NEC 690.12 (Rapid Shutdown) compliance[1]
  - Increased shade tolerance
  - Simplified PV system design
- MLPE market growing 14-18% annually [2]
- Need for explicit model to study power and energy impact

1 – NEC 690.12.c 2017
2 – The Global PV Inverter and MLPE Landscape H2 2016, S. Moskowitz, GTM 2016

What is PVMismatch?

- IV & PV curve trace calculator for PV system circuits[3]

3 – Mark Mikofski, Bennet Meyers, Chetan Chaudhari (2018). “PVMismatch Project: https://github.com/SunPower/PVMismatch". SunPower Corporation, Richmond, CA.

What is PVMismatch?

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- Model chain
  - **Cell > Cell string > Module > String > System**
  - Module layout

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  - Bypass diodes
- Model inputs
  - Cell technology characteristics
  - Irradiance (suns)
  - Temperature (cell temperature)
  - Bypass device configuration

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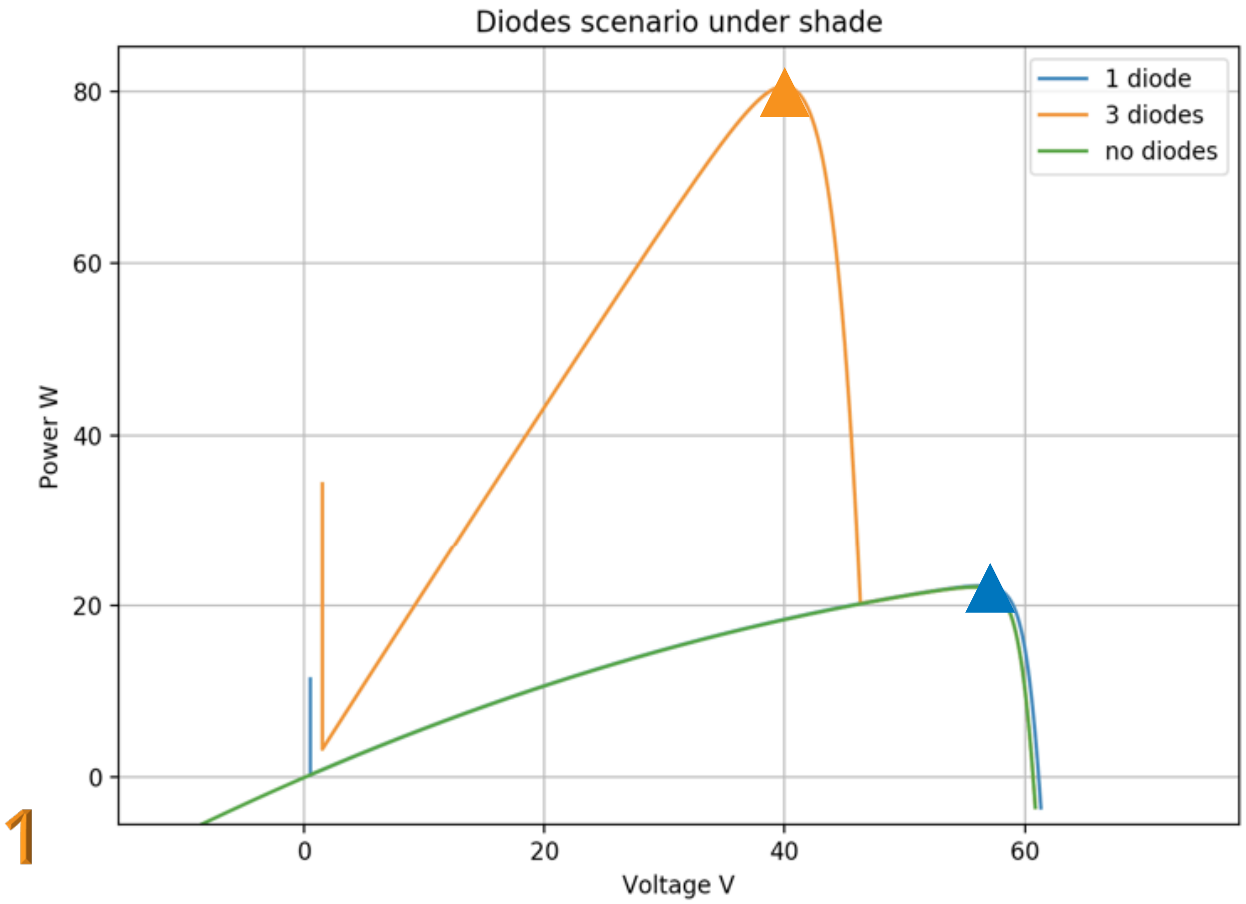
NEW!

Release > v4.1



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How to use?

```
>>> from pvmismatch import *  # this imports everything we need
>>> pvsys = pvsystem.PVsystem(numberStrs=2, numberMods=8)  # makes the
>>> from matplotlib import pyplot as plt  # now lets make some plots
>>> plt.ion()  # this turns on interactive plotting
>>> f = pvsys.plotSys()  # creates a figure with the system IV & PV cu

>>> pvsys.Vmp  # max voltage [V]
434.78820171467481

>>> pvsys.Imp  # max current [A]
11.821752935151656

>>>pvsys.Pmp  # max power [W]
5139.9586997897668

>>> pvsys.FF  # fill factor
0.78720728660102768

>>> pvsys.eff  # efficiency
0.21824347997841023

>>> pvsys.Voc  # open circuit voltage [V]
517.7428517321761

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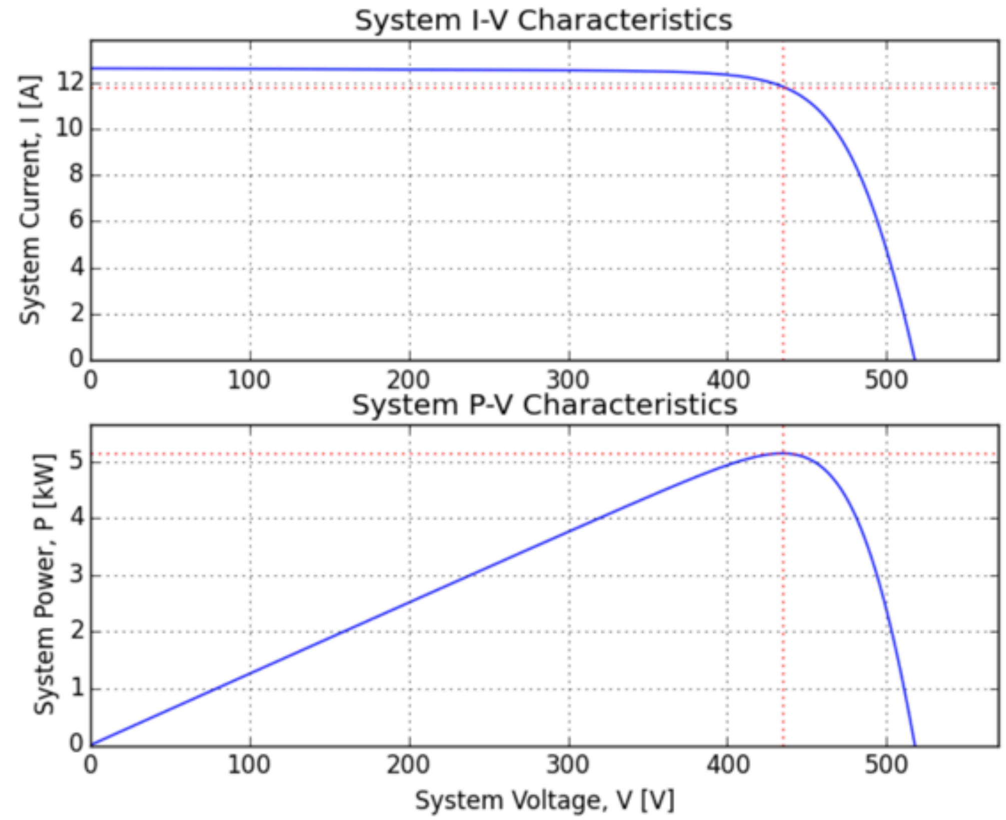
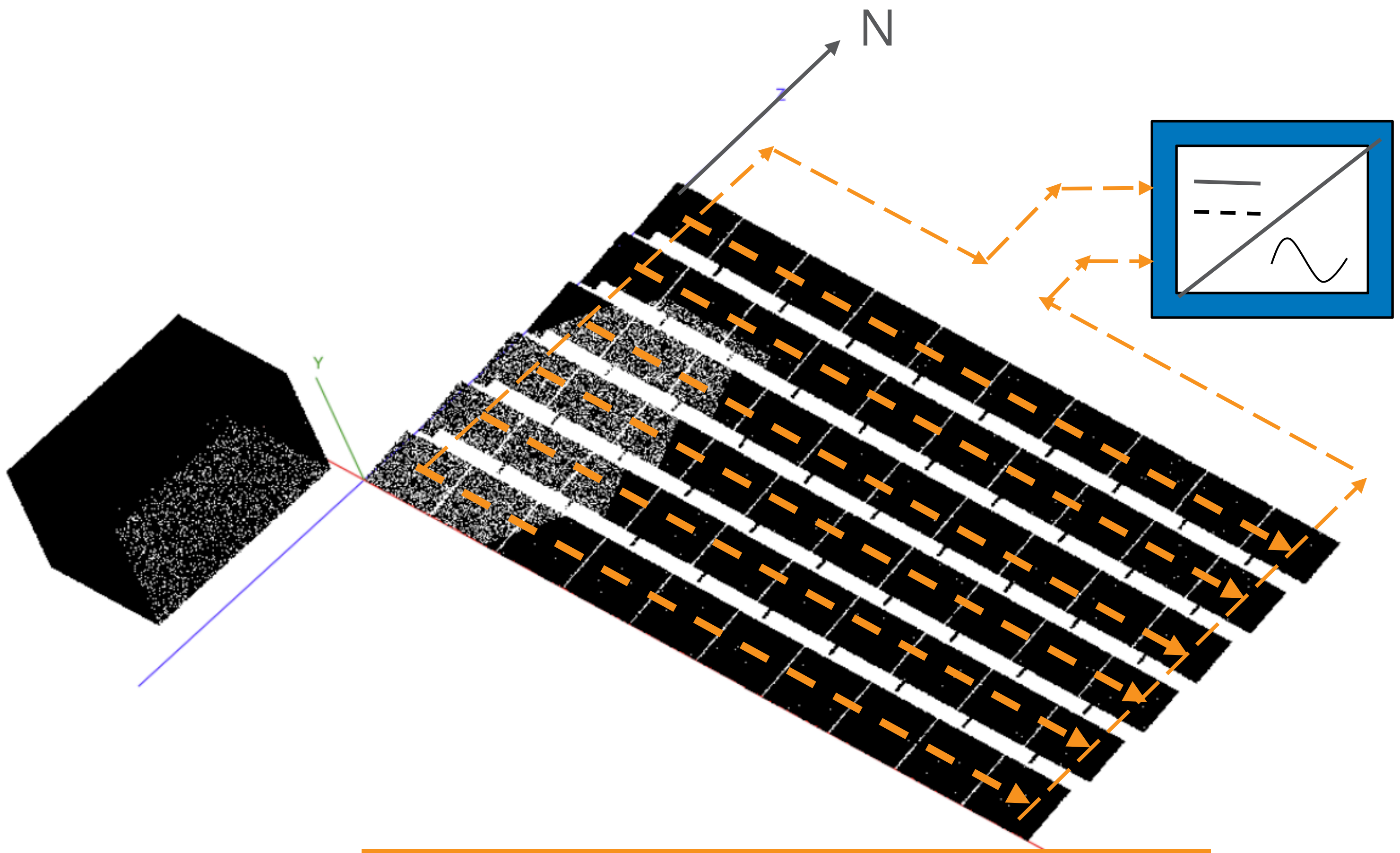


Case study

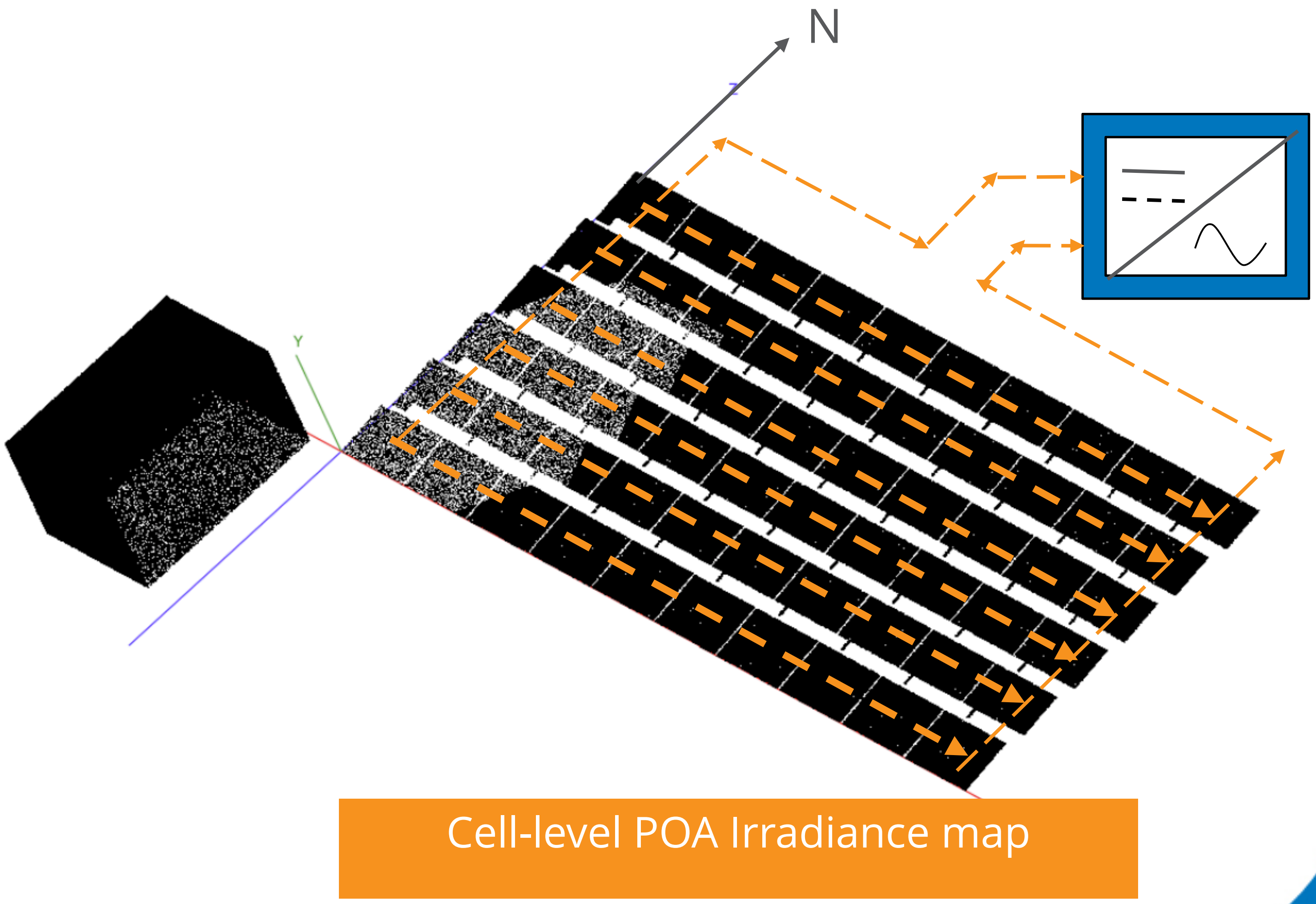
- Scenarios
  - String inverter
  - Power optimizers + String inverter
  - Microinverters



Cell-level POA Irradiance map

Case study

- Scenarios
  - String inverter
  - Power optimizers + String inverter
  - Microinverters
- System configuration
  - 10 modules x 6 strings
  - Azimuth = South
  - Tilt = 10 degree
  - Location = Richmond, CA
- Shade
  - Obstacle (SW)
  - Inter row



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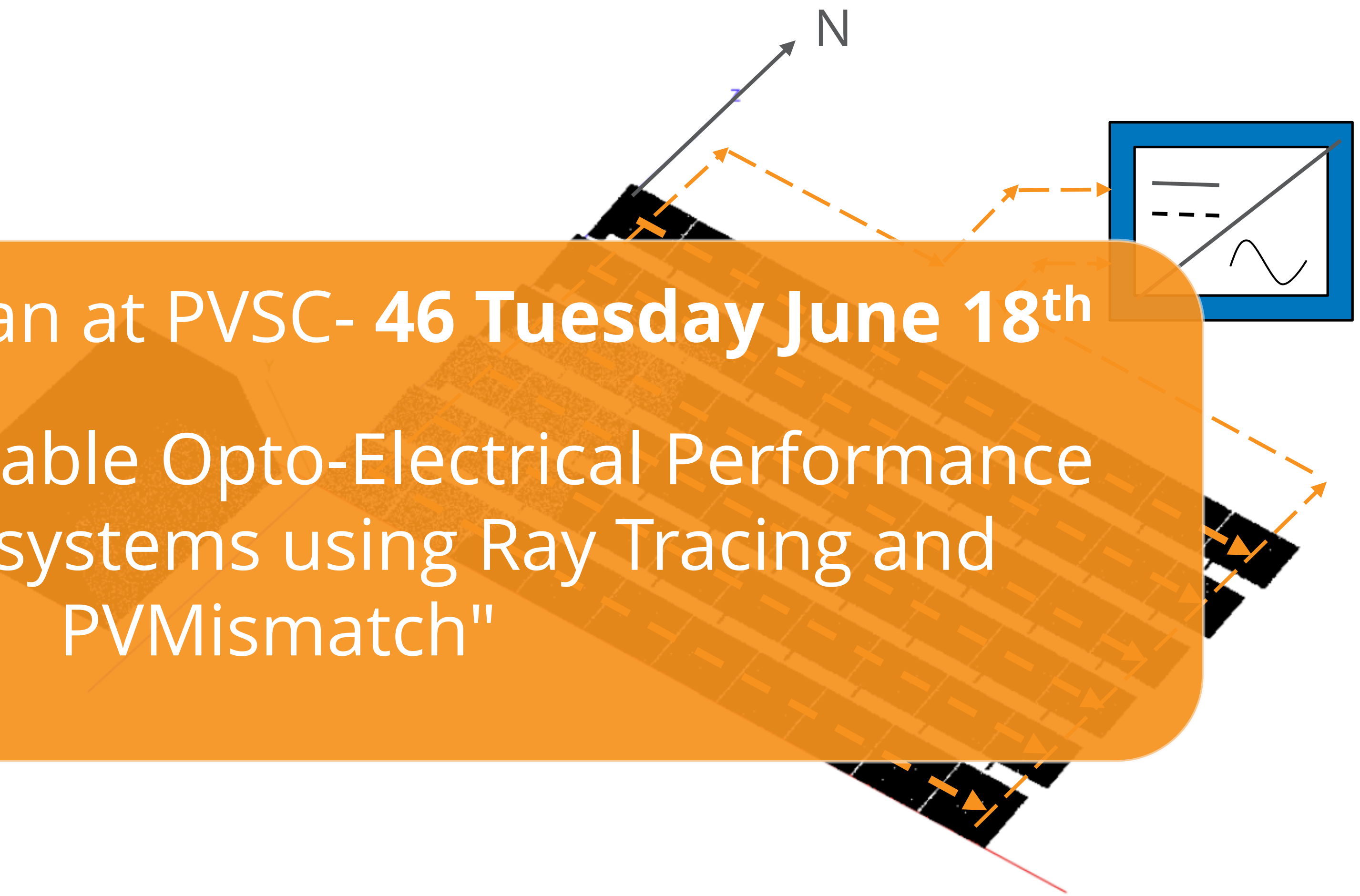


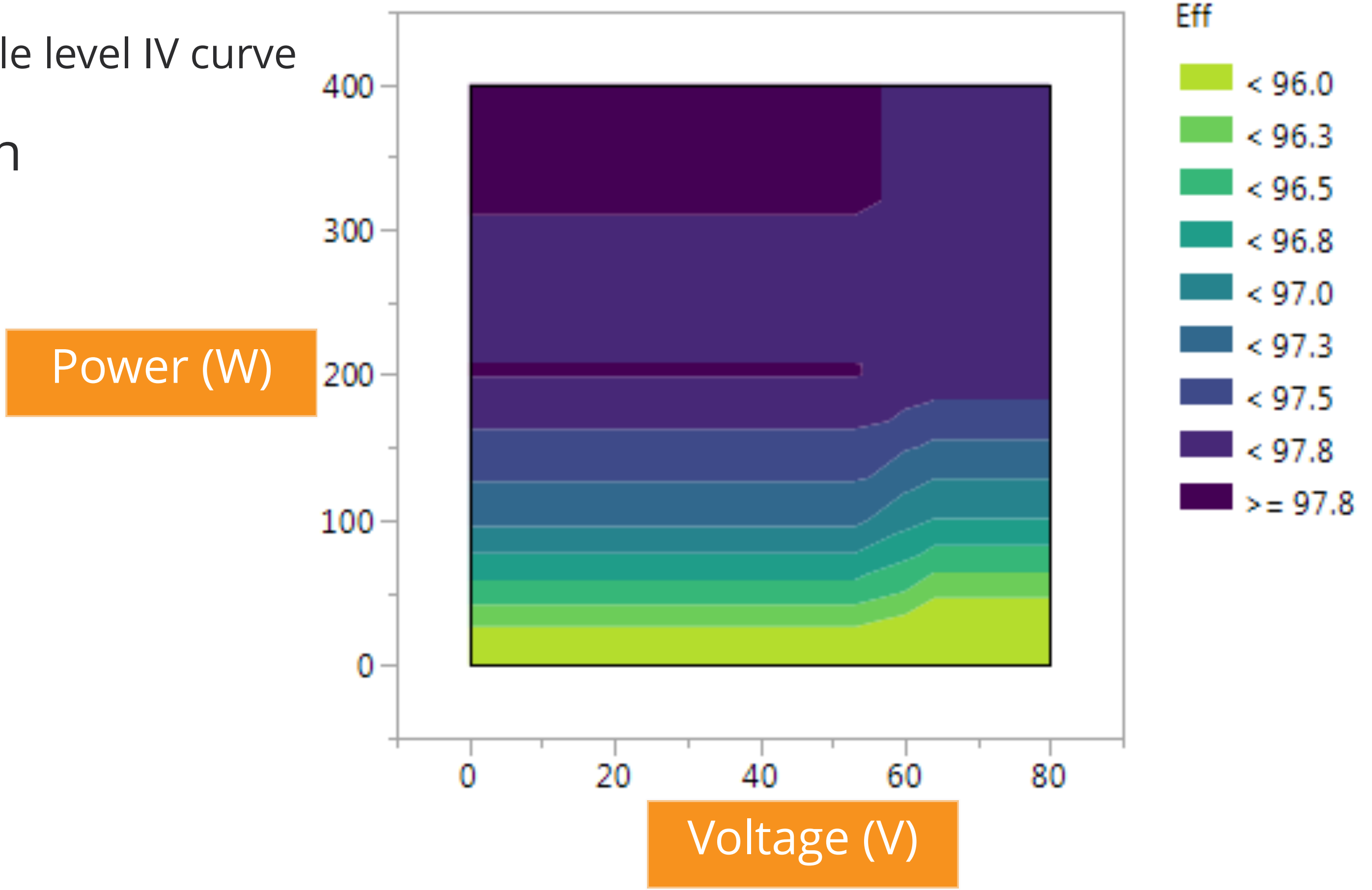
Come see Chetan at PVSC- **46 Tuesday June 18th**

"PVOPEL: A Scalable Opto-Electrical Performance Model of PV systems using Ray Tracing and PVMismatch"

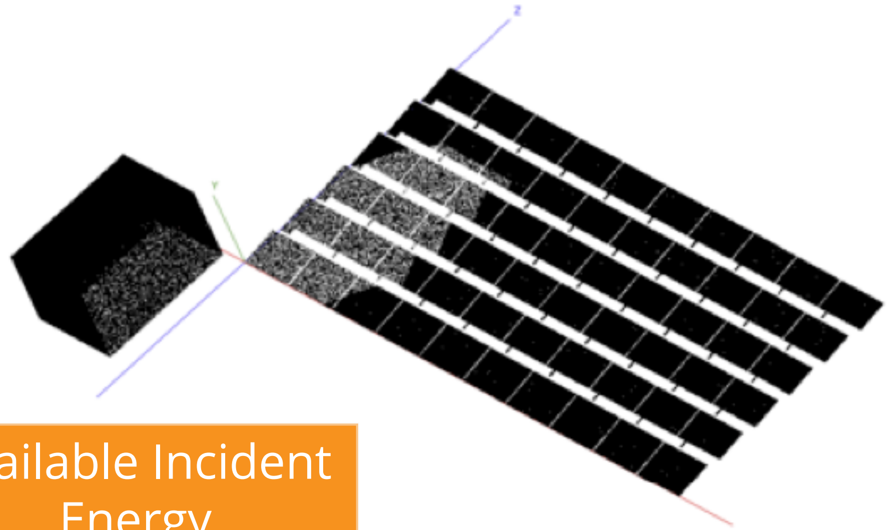
Microinverters

- **Key considerations**
  - Microinverter efficiency applied at module level IV curve
- Microinverter efficiency depends on
  - Power level or I_{mp}
  - Input Voltage (V_{mp})
  - Temperature (T_{amb})
  - Grid conditions
- Typically
  - lower power levels => lower efficiency
  - lower input voltage => lower efficiency

Contour plot for efficiency (microinverter)



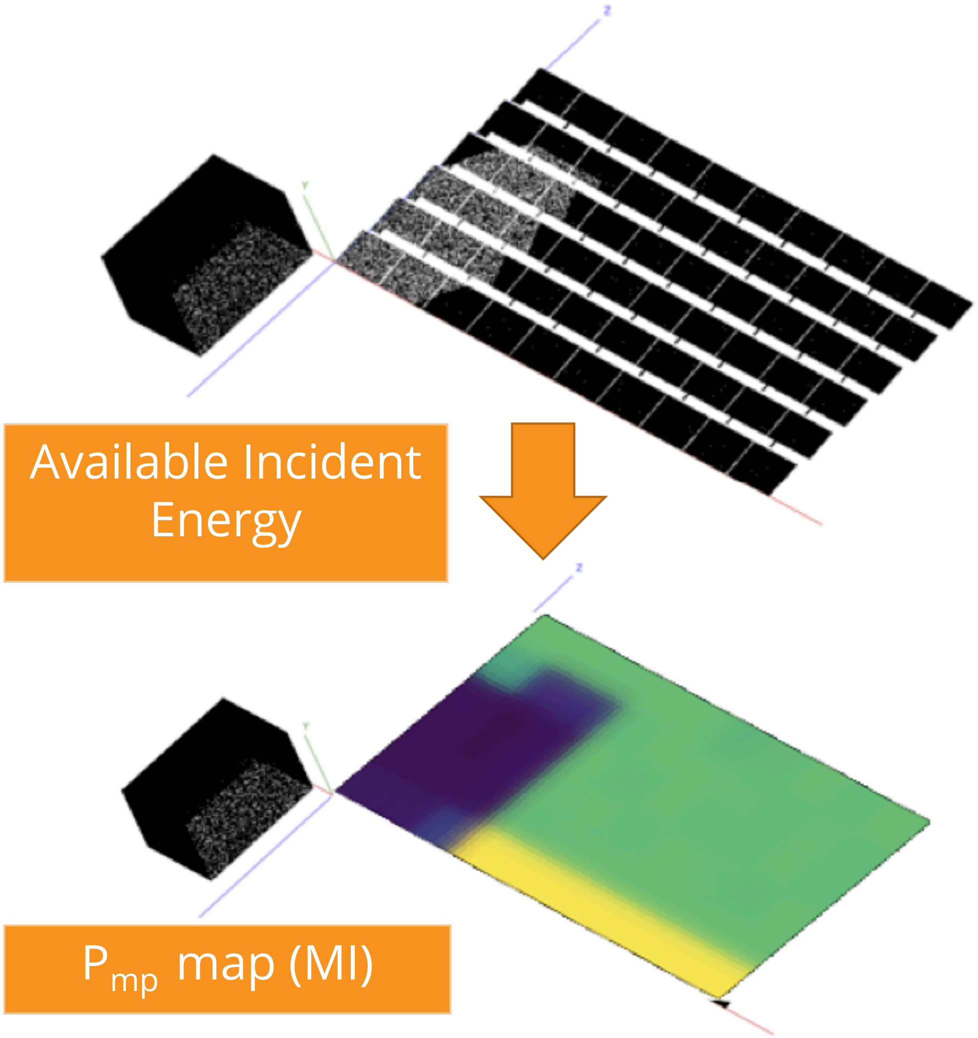
Microinverters - method



Available Incident Energy

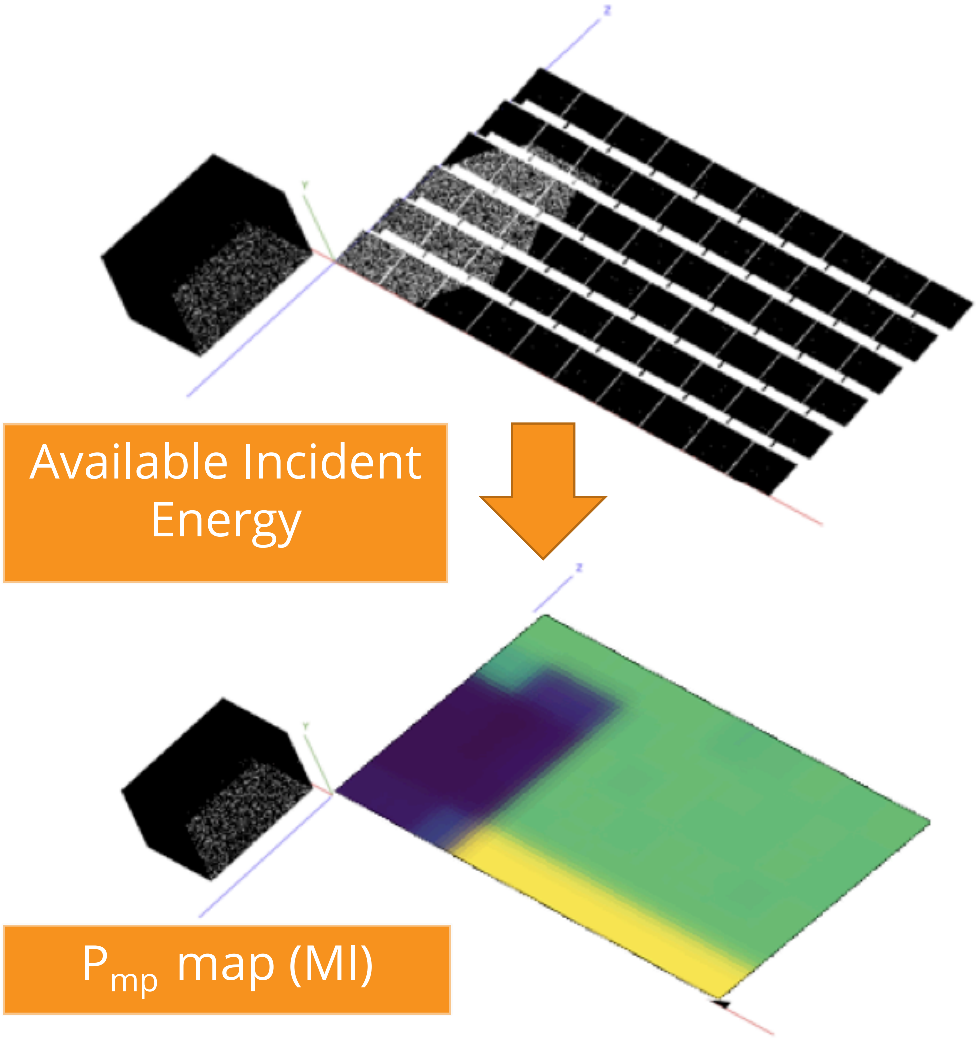
1. Find MPP of each module for given irradiance conditions

Microinverters - method



1. Find MPP of each module for given irradiance conditions
2. Find efficiency loss for that power level
3. Calculate $P_{mpmod[MI]}$

Microinverters - method



1. Find MPP of each module for given irradiance conditions
2. Find efficiency loss for that power level
3. Calculate $P_{mpmod[MI]}$
4. Sum the $P_{mpmod[MI]}$ across the array to get P_{mpsys}

Microinverters - equations

$$P_{mpsys} = \sum_{n=0}^{N} P_{mpmod}[n] \times MIEff(P_{mpmod}[n], V_{mpmod}[n])$$

Where

N : number of PV modules

P_{mpsys} *: System Power*

P_{mpmod} *: module power at max. power point*

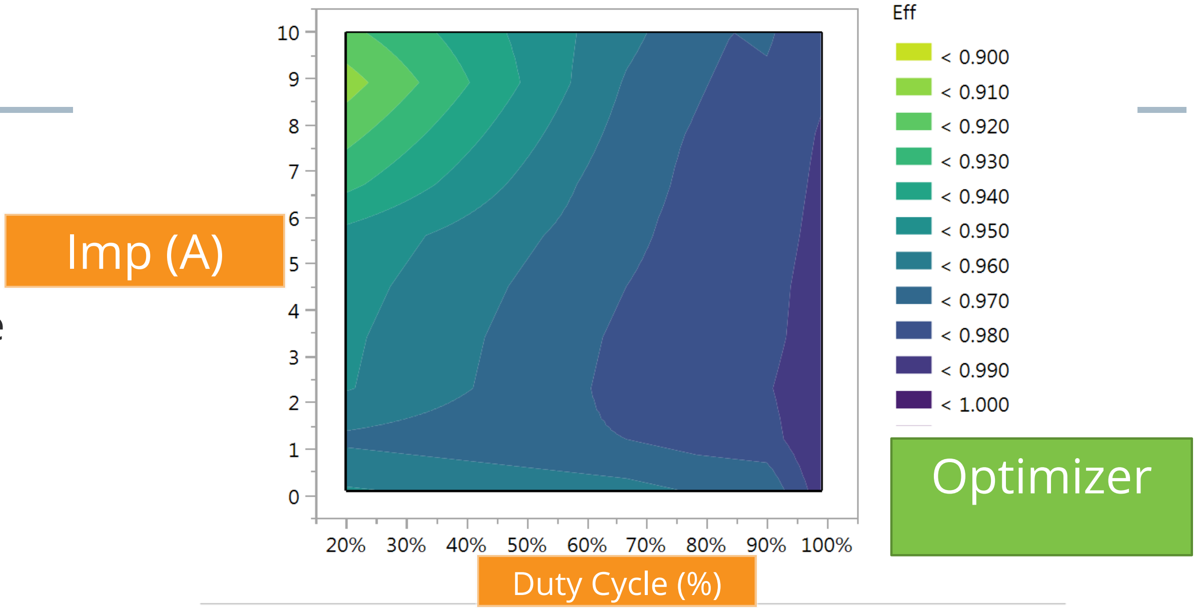
V_{mpmod} *: module voltage at max. power point*

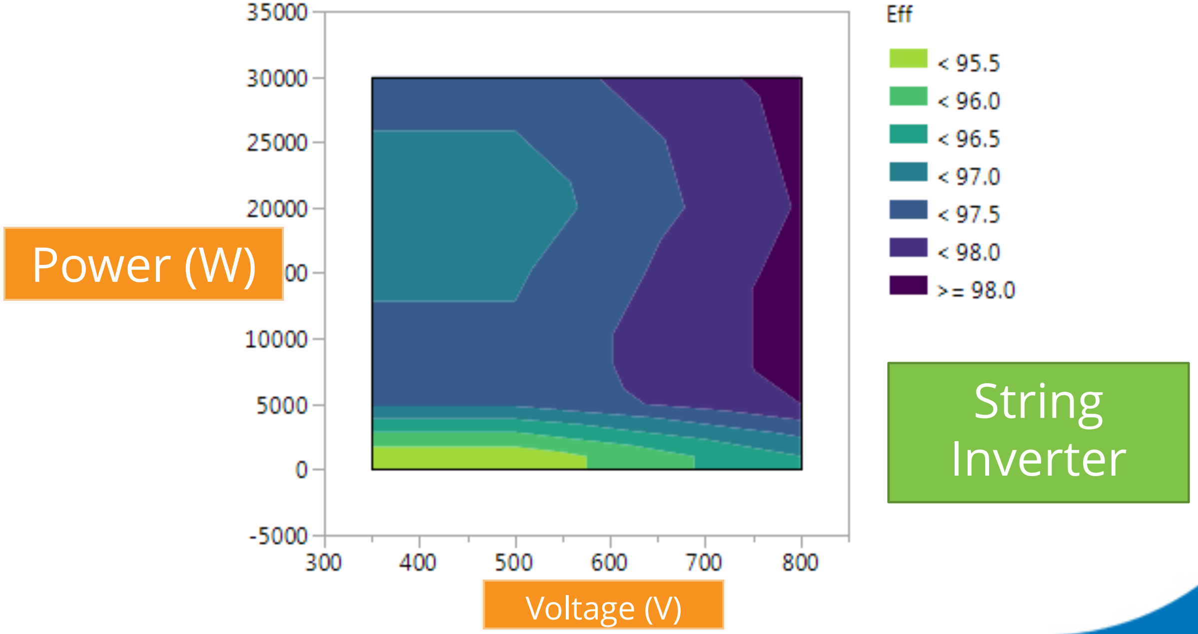
MIEff(power, voltage) : microinverter efficiency at given operating point

DC optimizers

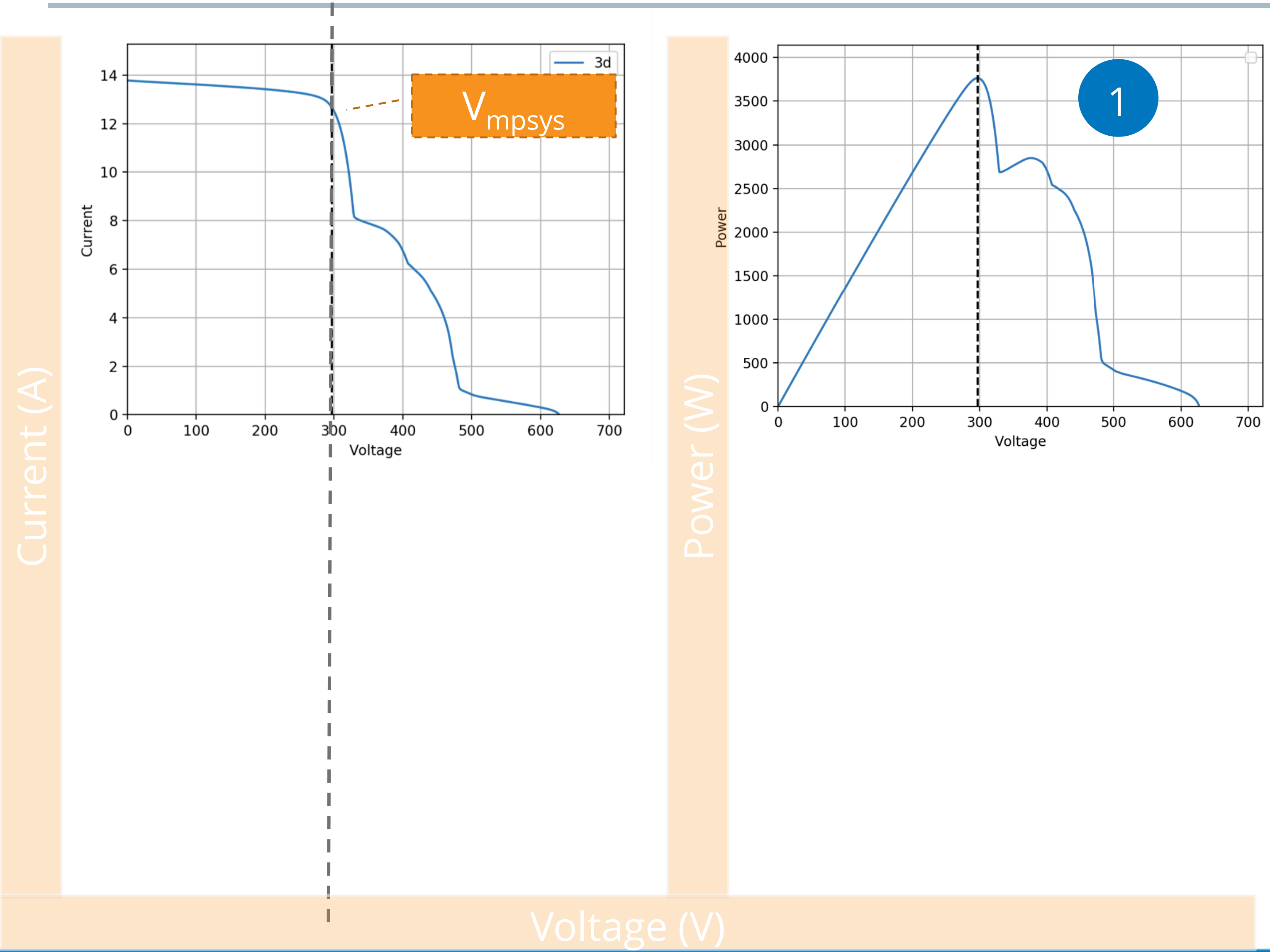
- **Key considerations**
  - Corrects for module to module mismatch
  - Optimizer efficiency applied at module level IV curve
  - Inverter efficiency applied at MPPT circuit level
- Optimizer efficiency depends on
  - Power level or I_{mp}
  - Duty Cycle = $I_{in}/I_{out} = I_{mp}/I_{out}$
    - Where $I_{out} = I_{string}$ @V_{mpsys}
  - Temperature (T_{amb})
  - Input Voltage (V_{mp})
- Typically for power converters -
  - lower power levels => lower efficiency
  - lower duty cycles => lower efficiency

Contour plots for efficiency



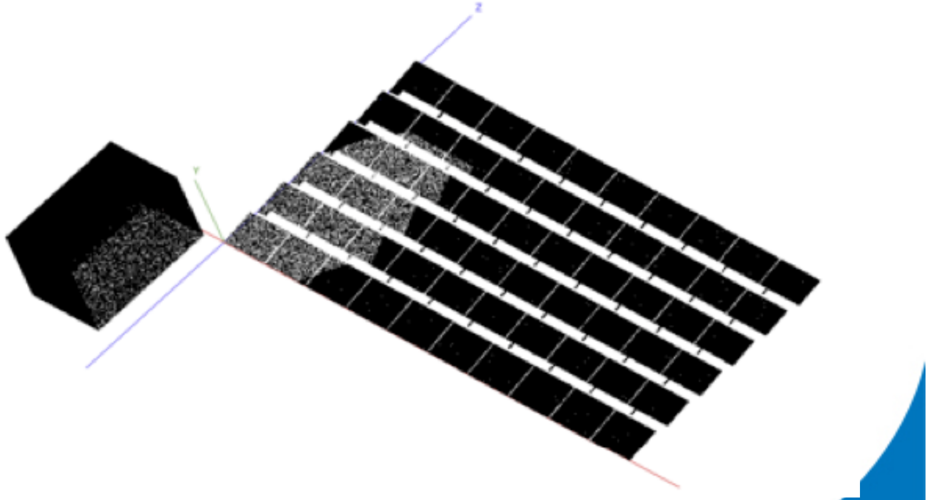


DC optimizers - method



Finding operating points of optimizers

1. Find MPP of system level PV curve from 1
2. Assume the corresponding V_{mpsys} as string voltage for all strings since they are in parallel



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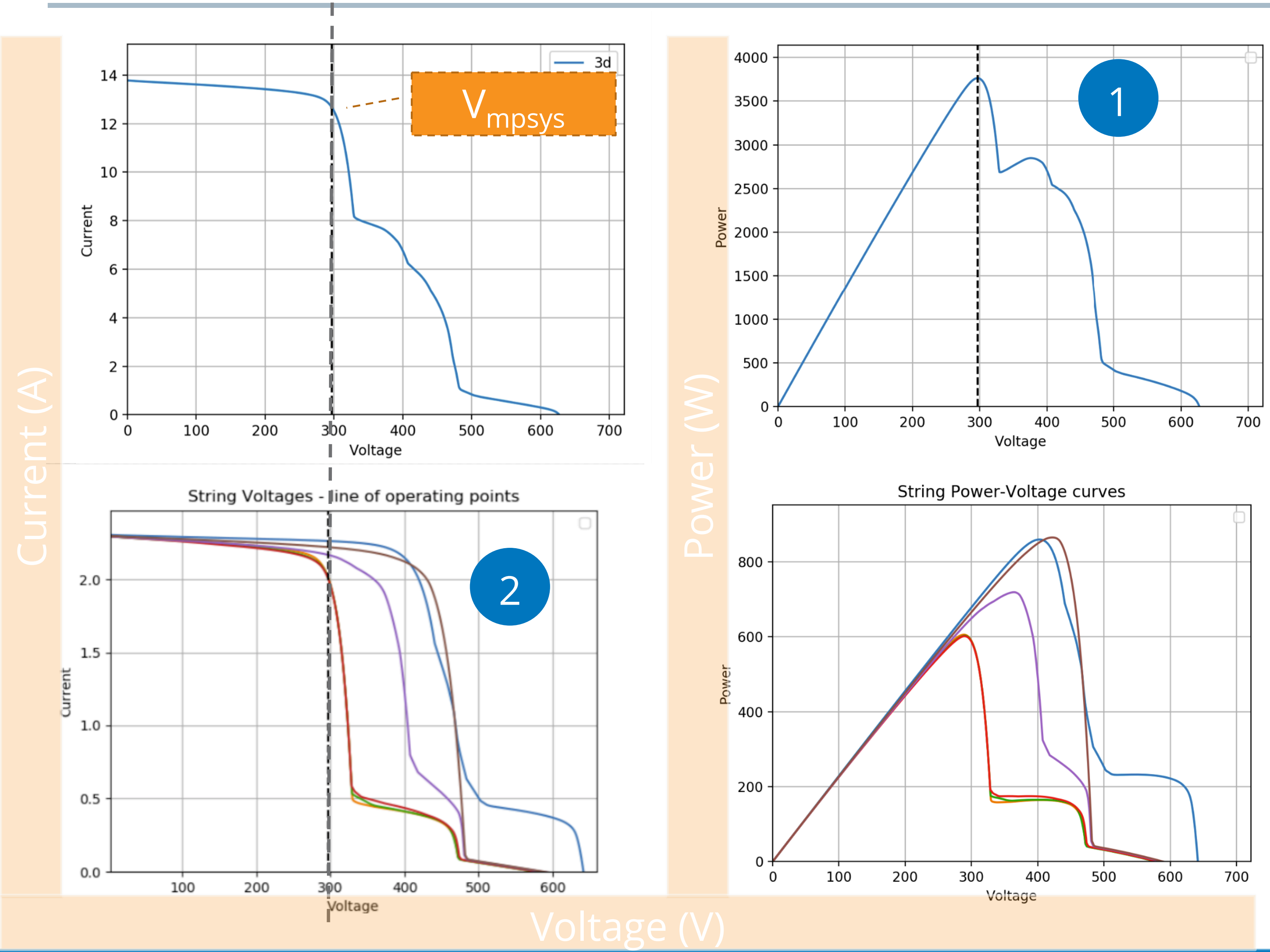
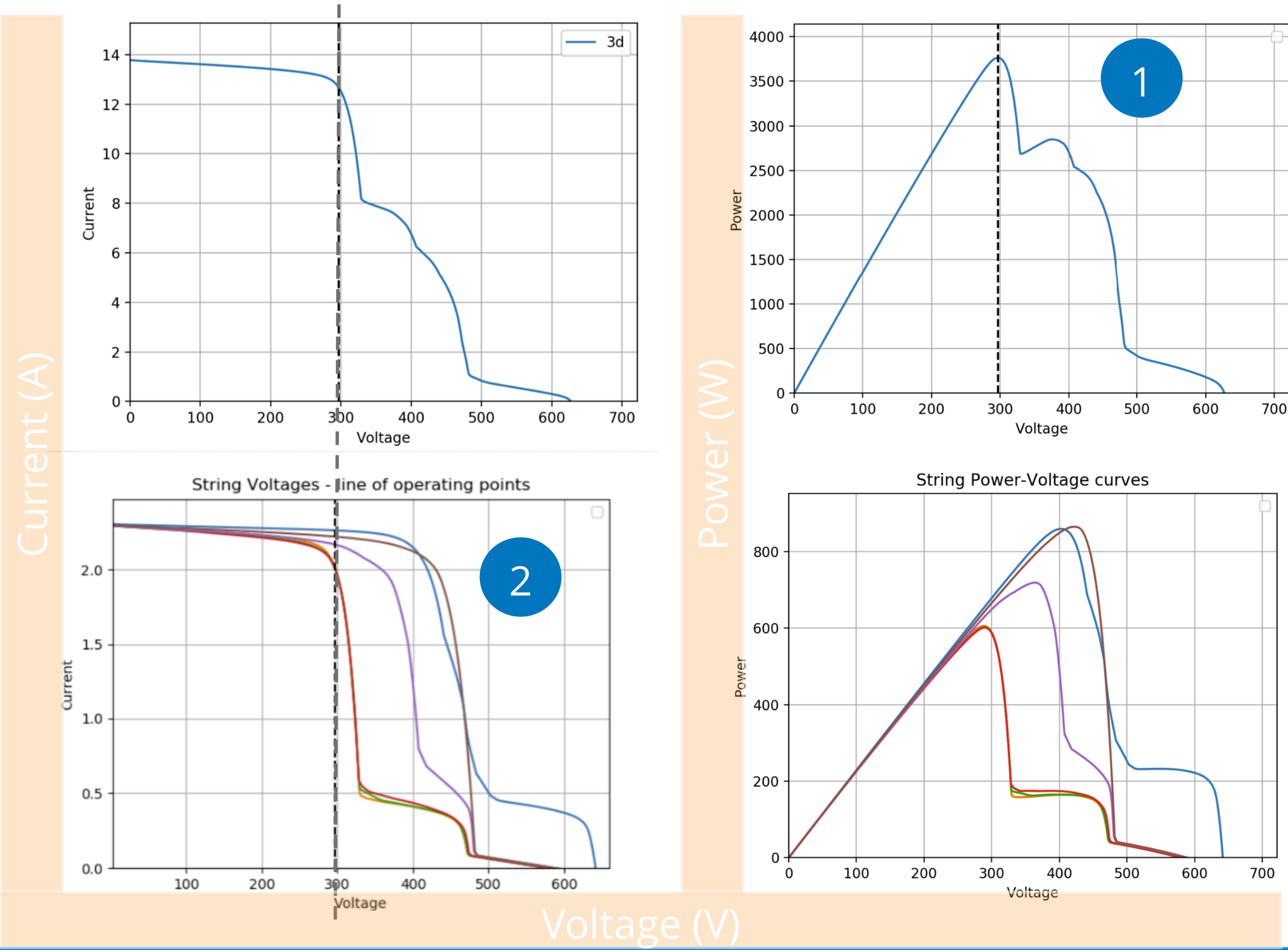


Finding operating points of optimizers

1. Find MPP of system level PV curve from 1
2. Assume the V_{mpsys} as string voltage for all strings
3. Find I_{out} for each string by locating I_{string} from 2 for V_{mpsys} (dotted line)

DC optimizers - method



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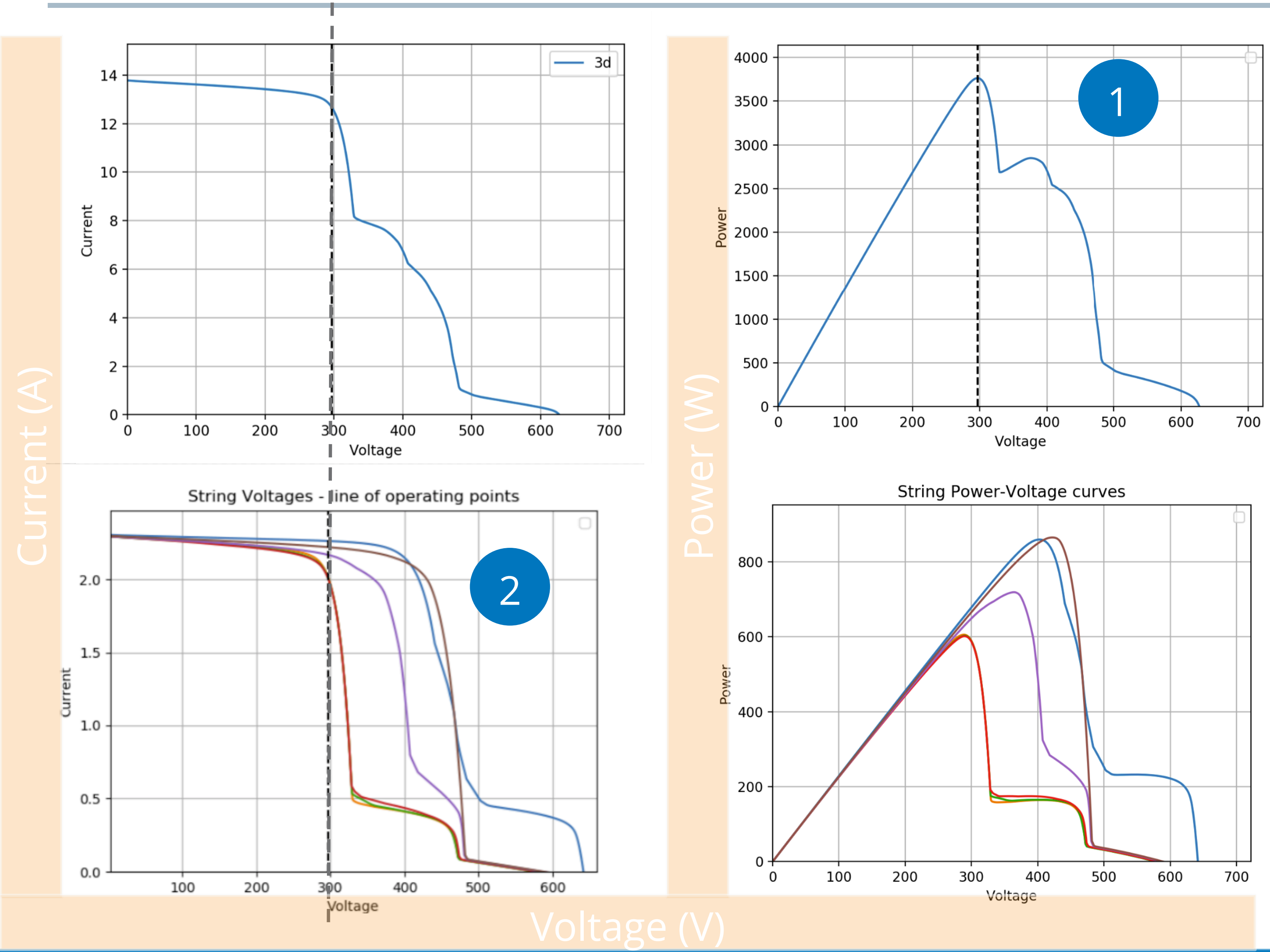

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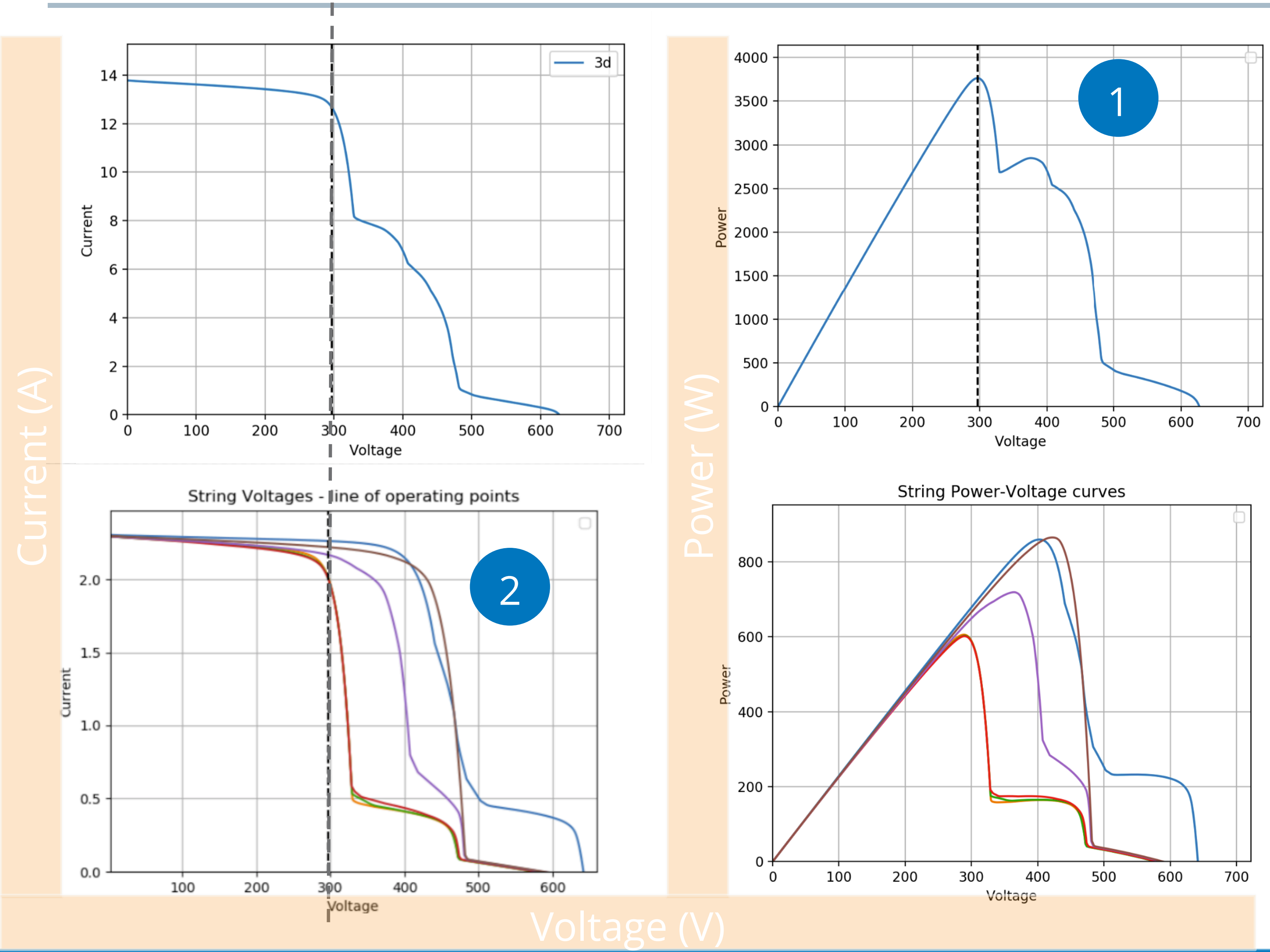

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5. Sum the $P_{mpmod[OPT]}$ to get $P_{mpsys[OPT]}$
6. Apply String inverter efficiency to get power value

DC optimizers - equations

$$I_{string}[str] = I_{sys}[V_{mpsys}] \qquad \dots (1)$$

$$DutyCycle[n] = {I_{mp}[n]}/{I_{string}[str]} \qquad \dots (2)$$

$$P_{mod}[n] = P_{mpmod}[n] * OptEff(DutyCyle[n], I_{mpmod}[n]) \qquad \dots (3)$$

$$P_{sys} = (\sum_{n=0}^{N} P_{mod}[n]) \times StrInvEff(P_{mpmod}[n], V_{mpmod}[n]) \qquad \dots (4)$$

Where

I_{sys} : PV system current (A)

V_{mpsys} : Voltage at max. power point - system level (V)

I_{mp} : module current at max. power point (A)

P_{mpmod}, V_{mpmod}, I_{mpmod} : module power, voltage and current at max. power point

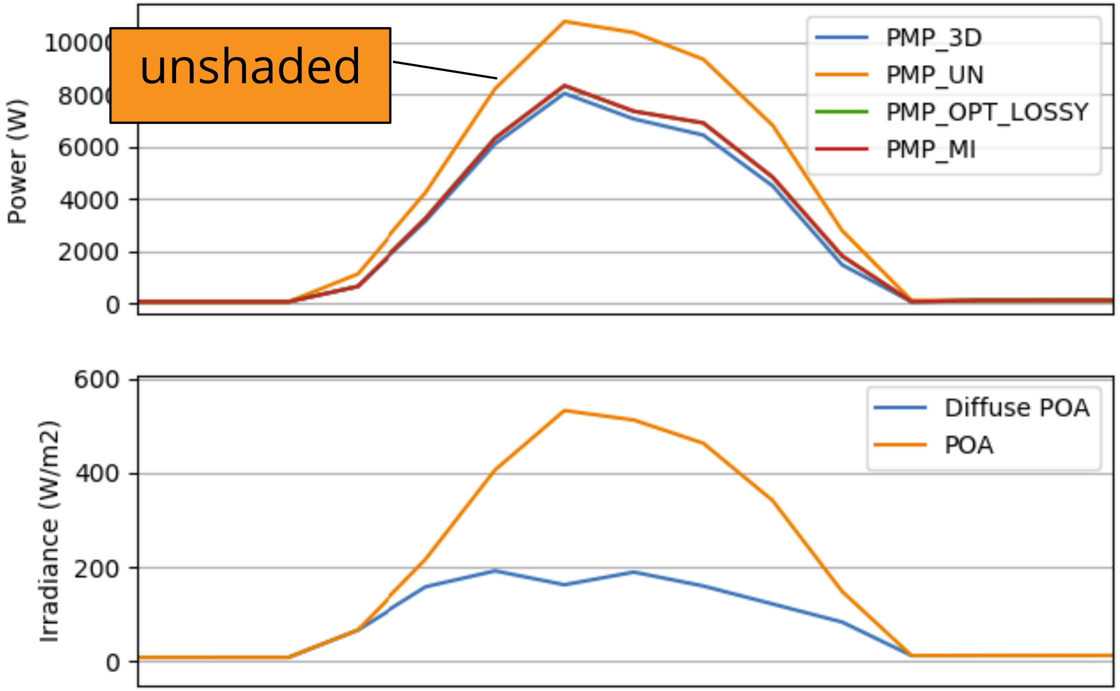
OptEff(duty cycle, input current) : optimizer efficiency at given duty cycle and input current (%)

StrInvEff(power, voltage) : string inverter efficiency at given input power and voltage (%)

P_{sys} : System Power

Results – Hourly

Typical winter day



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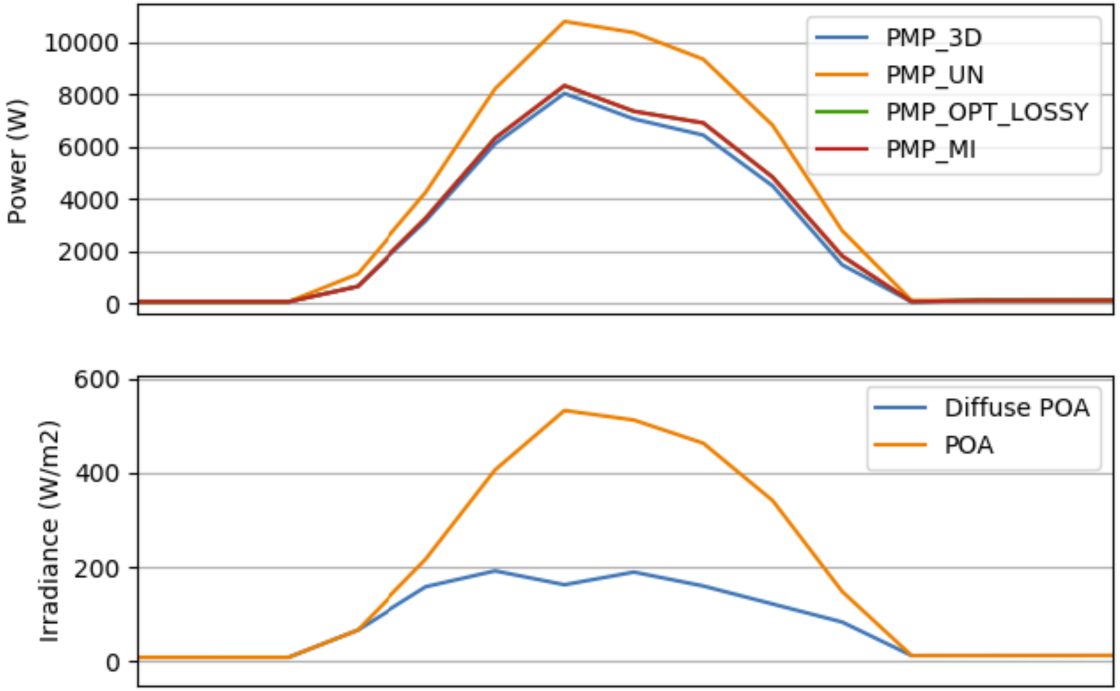
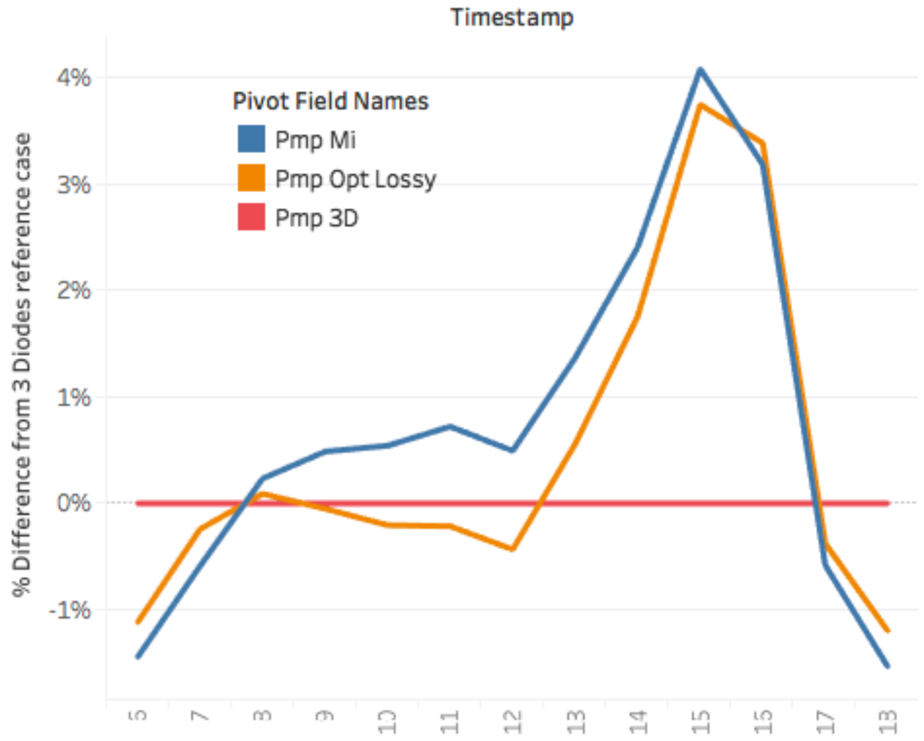


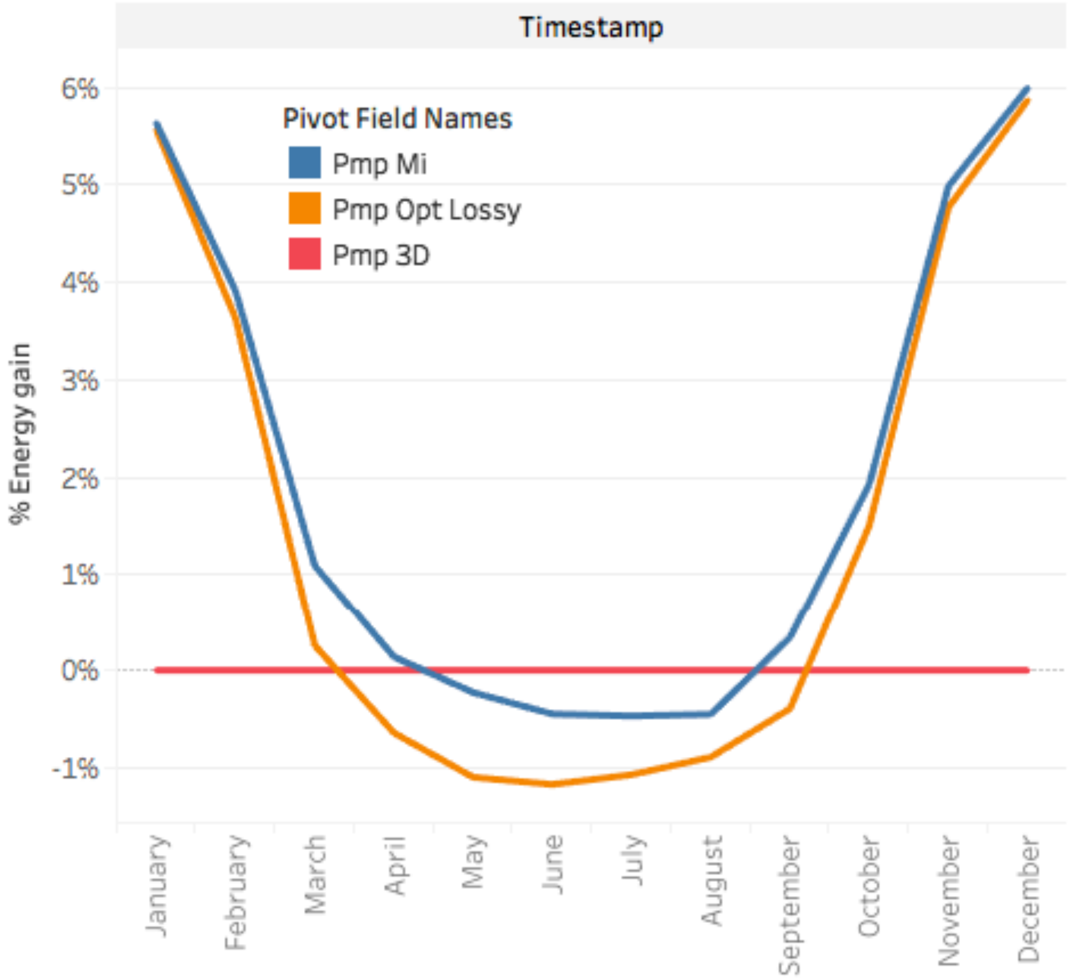
Annual energy by hour of day



- Since obstacle is South-West of the array, afternoon/evening shade is expected and thus the MLPE energy recovery is also in those hours of the day

Results – Monthly

MLPE monthly gain



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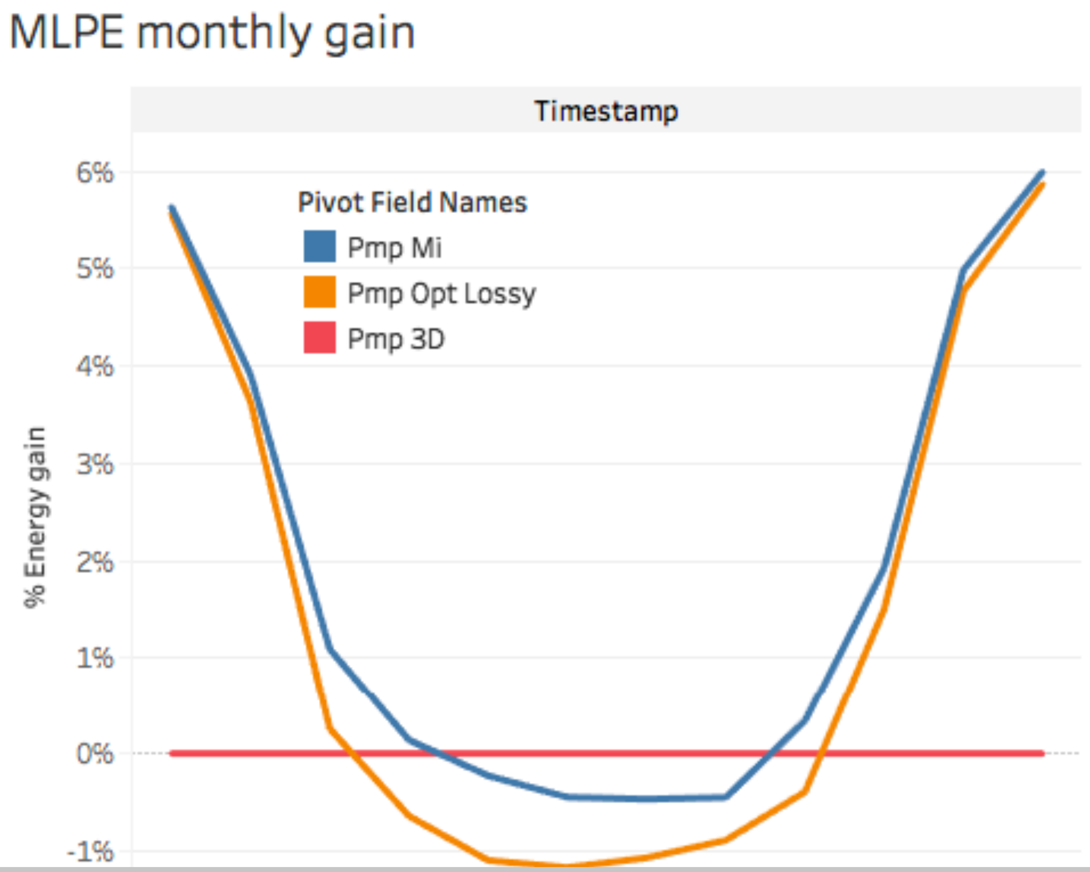
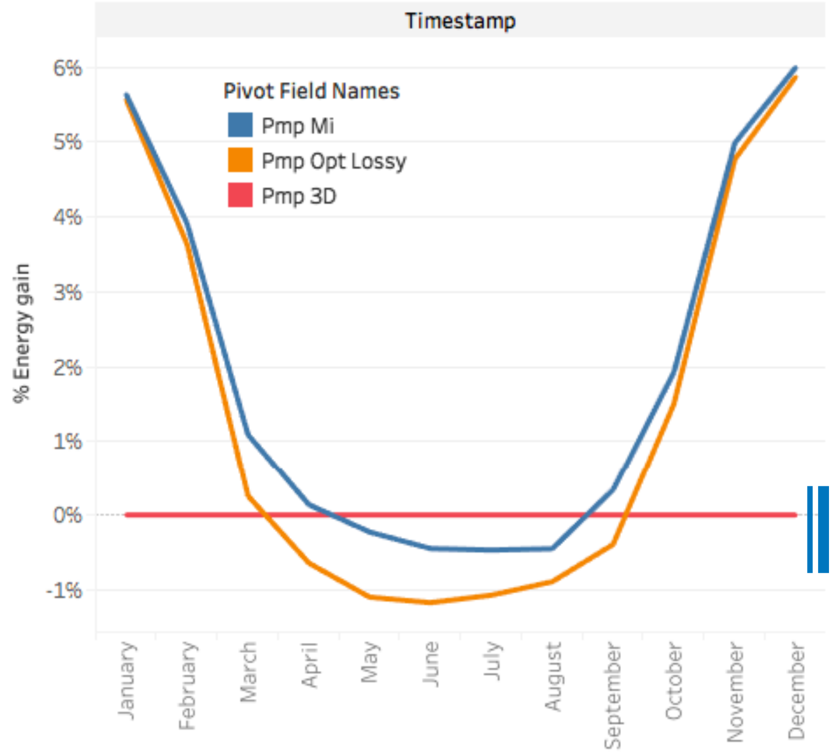
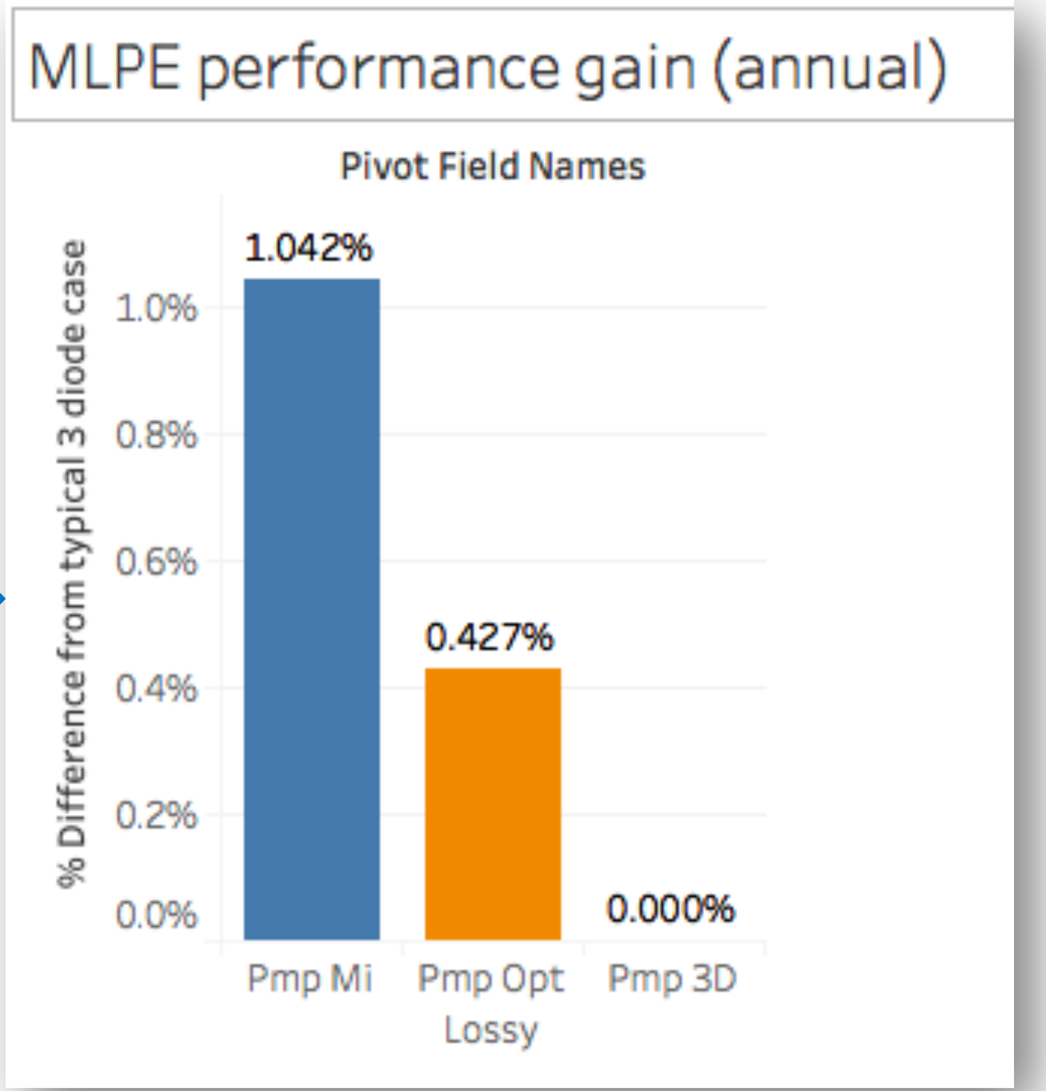


- Winter months can gain up to 6% energy using MI and Optimizers
- Summer months can see up to 1.5% losses in power train efficiency with lack of shading

Results – Annual

MLPE monthly gain





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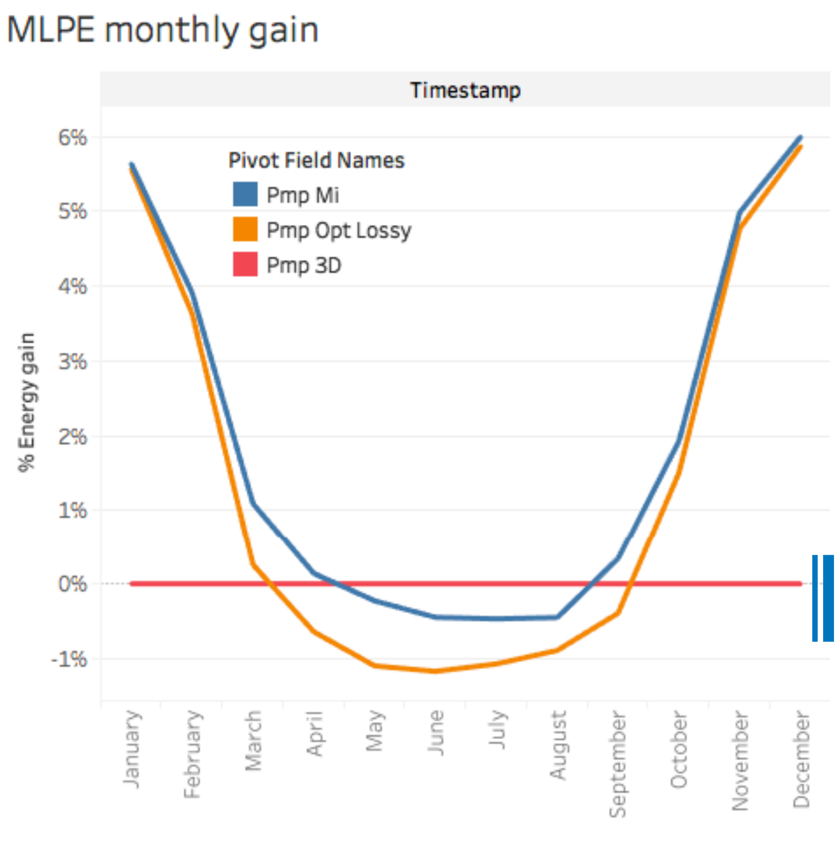

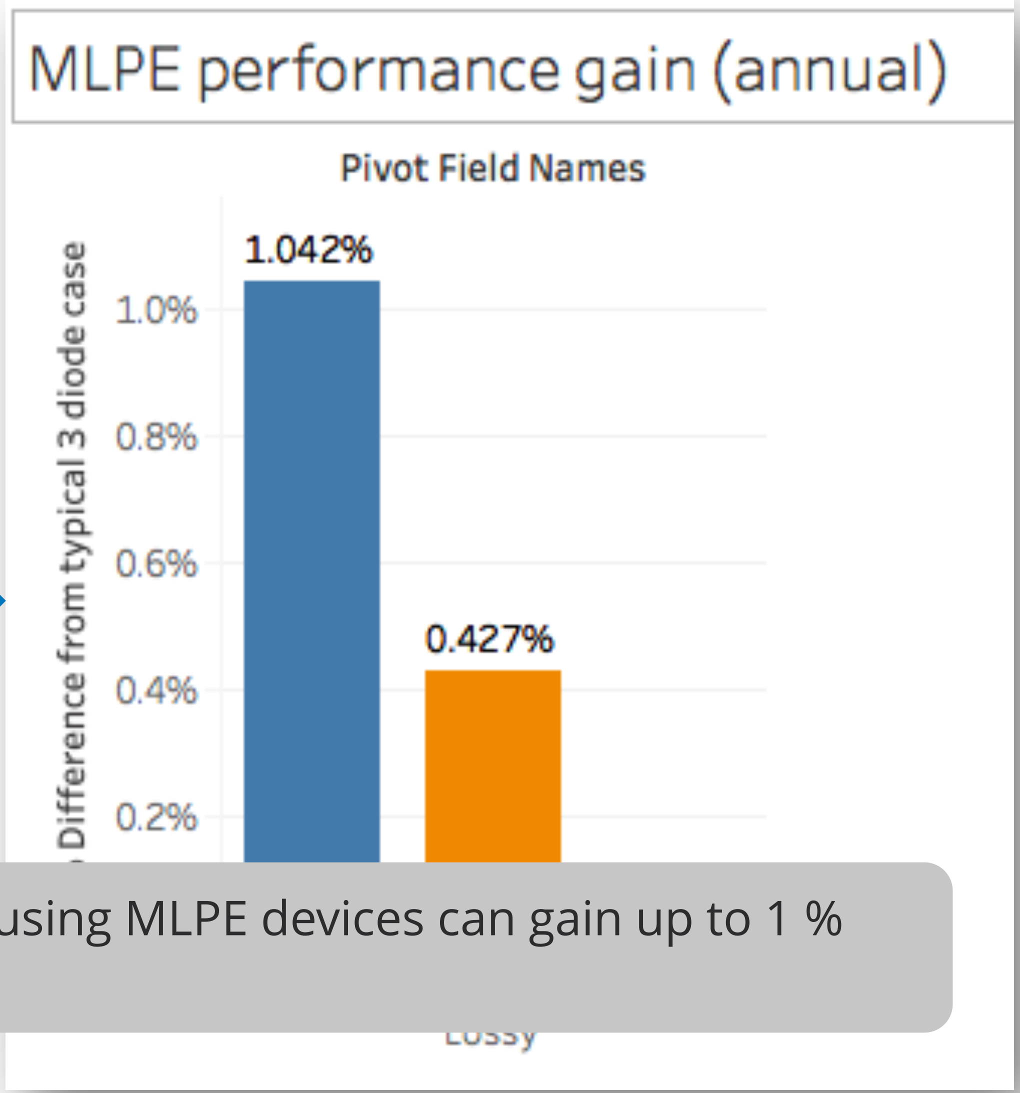

- On a shade constrained PV system in this study, using MLPE devices can gain up to 1 % more energy

Conclusions

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- Performance gains of MLPEs vary across the year for a given shading scene and annual energy gives the most accurate measure of their performance.

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- Performance gains of MLPEs vary across the year for a given shading scene and annual energy gives the most accurate measure of their performance.
- On a shade constrained PV system in this study, using MLPE devices can gain up to 1 % more energy annually

Acknowledgements

Special thanks to Mark Mikofski and Bennet Meyers for creating PVMismatch!

Thank You

Let’s change the way our world is powered.