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Simulation of low breakdown voltage cells in PVsyst

PVPMC Workshop

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Outline

Shading tolerance of low reverse breakdown voltage cells :

- Introduction
- Submodule IV curve construction
- Regular shading:
  - One submodule case
  - Twin half-cells case

Possibility of simulations in PVsyst :

- PVsyst «Partition model» mimick full I-V curves simulations for large regular system, featuring traditional modules.
- Question: Can the partition model be adapted to represent low RBV cells?

Discussion / Conclusion

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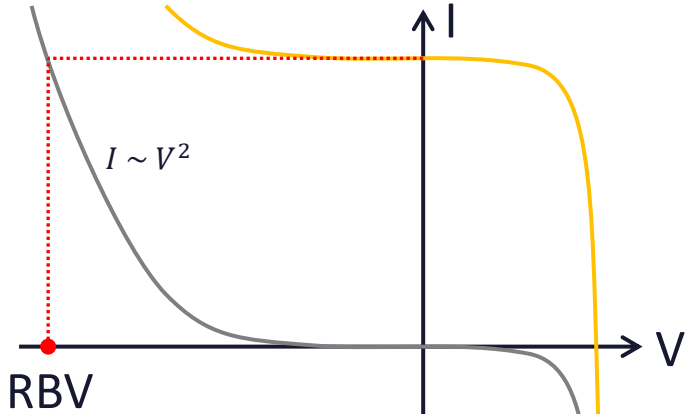
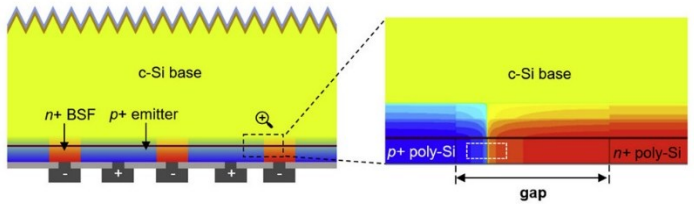
[1] Calcabrini, 10.1016/j.xcrp.2022.101155
[2] Schweigstill, 10.1051/epjpv/2021016
[3] Zhiwei, 10.1016/j.solener.2025.113818

Solar cells with Low Reverse Breakdown voltage (RBV)

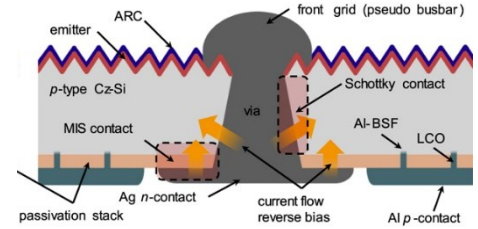
Low RBV Solar cell I-V curve (illuminated and dark)



Examples of solar cell technology allowing low RBV

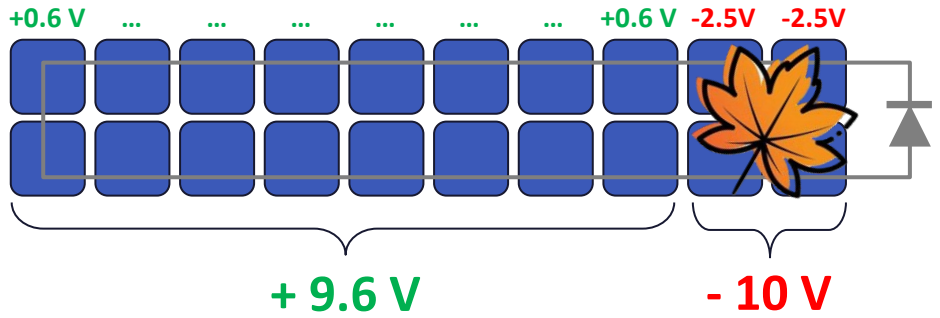


Back-contact cells with overlapping p- and n-contacts, forming a tunnel junction [1].



Metal Wrap Through cells interconnection, forming a Schottky diode [2].

- At RBV, a large current can flow.
- Traditional c-Si: RBV = -10 to -30V
  - Large power dissipation
  - By-pass diode (BPD) mandatory
- Low RBV cell technology:
  - Lower power dissipation (hot spot reduction)
  - The cell «operates as its own BPD»
- Technological limitations:
  - Low RBV comes at the expense of decreased efficiency (shunts).
  - Commercial technologies: RBV = -2.5V to -5.0V
- Low RBV outperforms reference when < 3-4 shaded cells [3]



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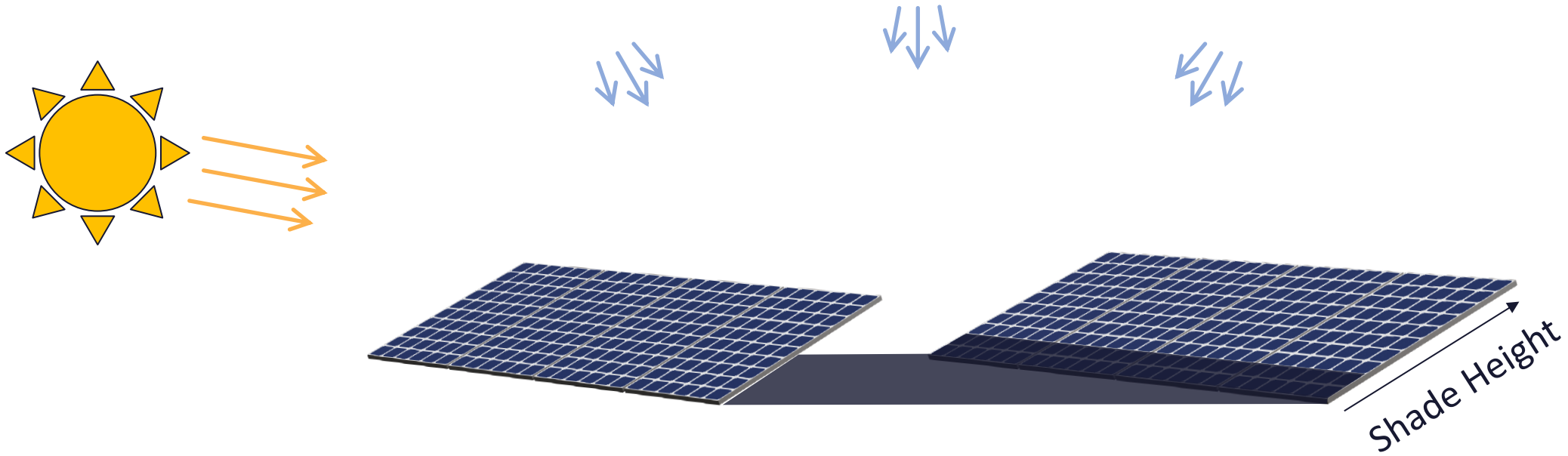
Shading scenarios considered : Row to Row shading

Working hypothesis:

- Direct light: shaded progressively from the lower part of the modules.
- Diffuse light: unshaded.
- Regular shading: same shading for ALL modules in the string.



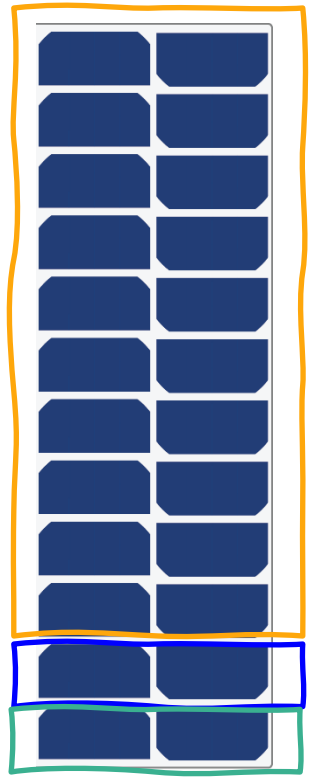
Submodule IV curve of low RBV cells

Ncells = 24

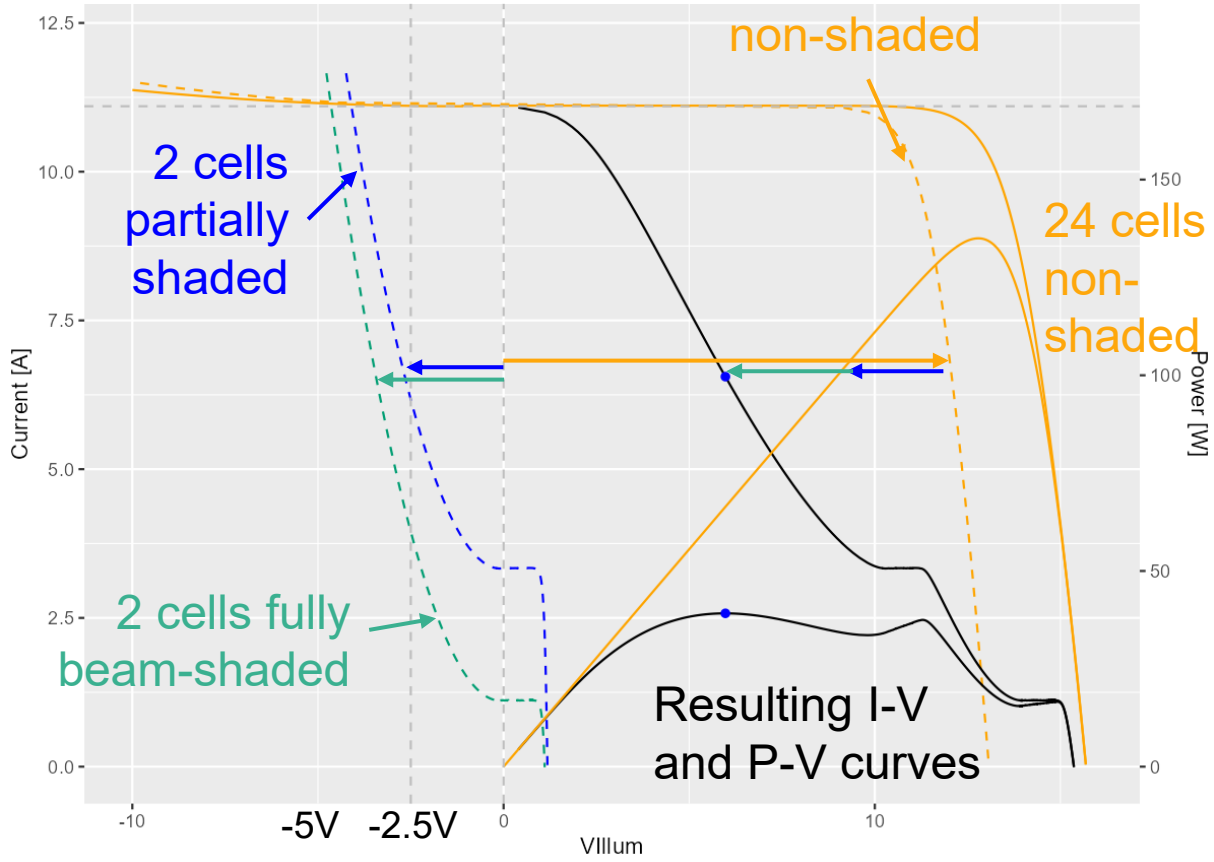
20 Fully illum. cells

2 Partially beam-shaded cells

2 Fully beam-shaded cells
(only diffuse light)



Reverse characteristic ~ V^2



Exact I-V curve constructions unveils complex properties

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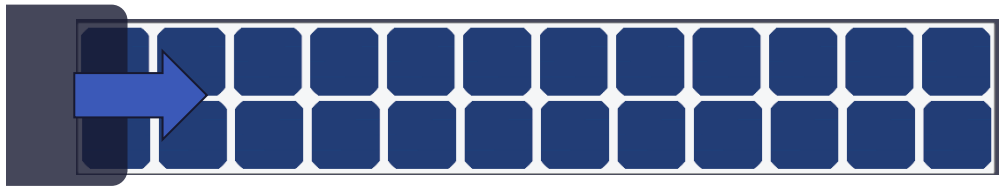
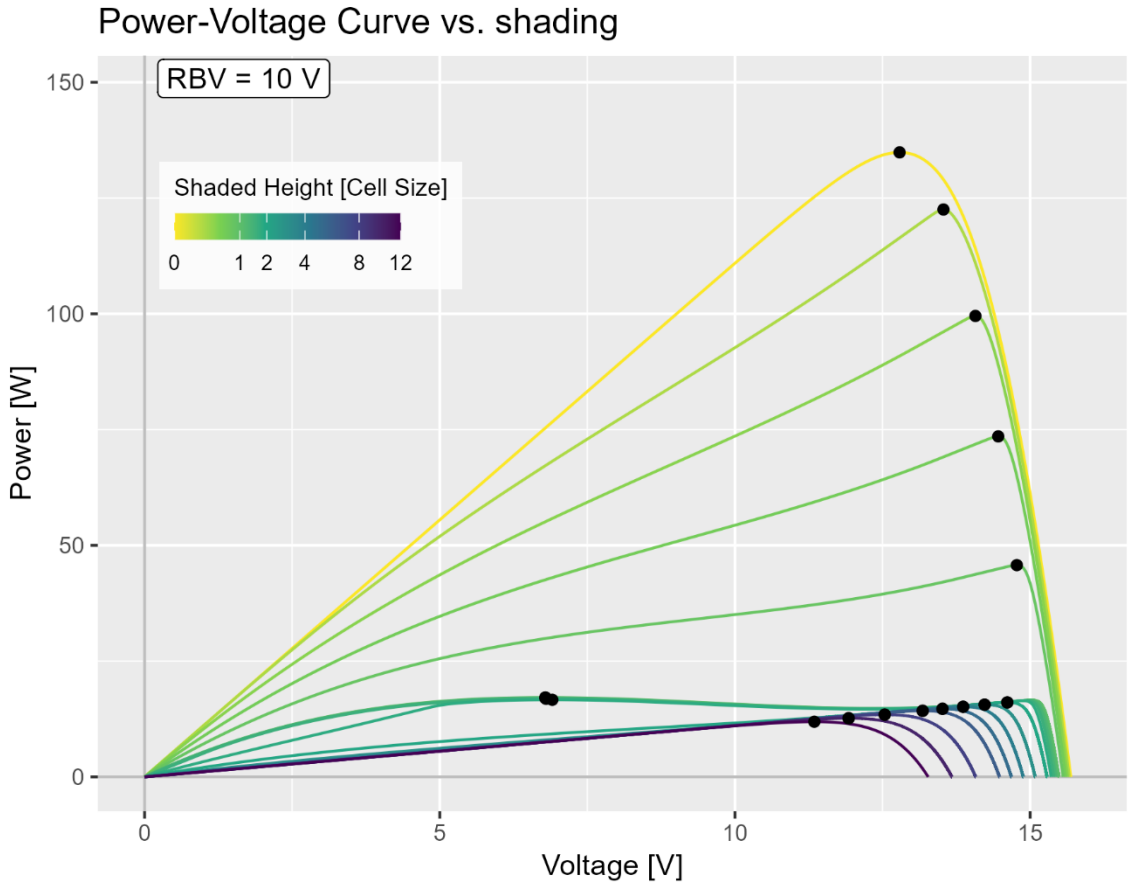
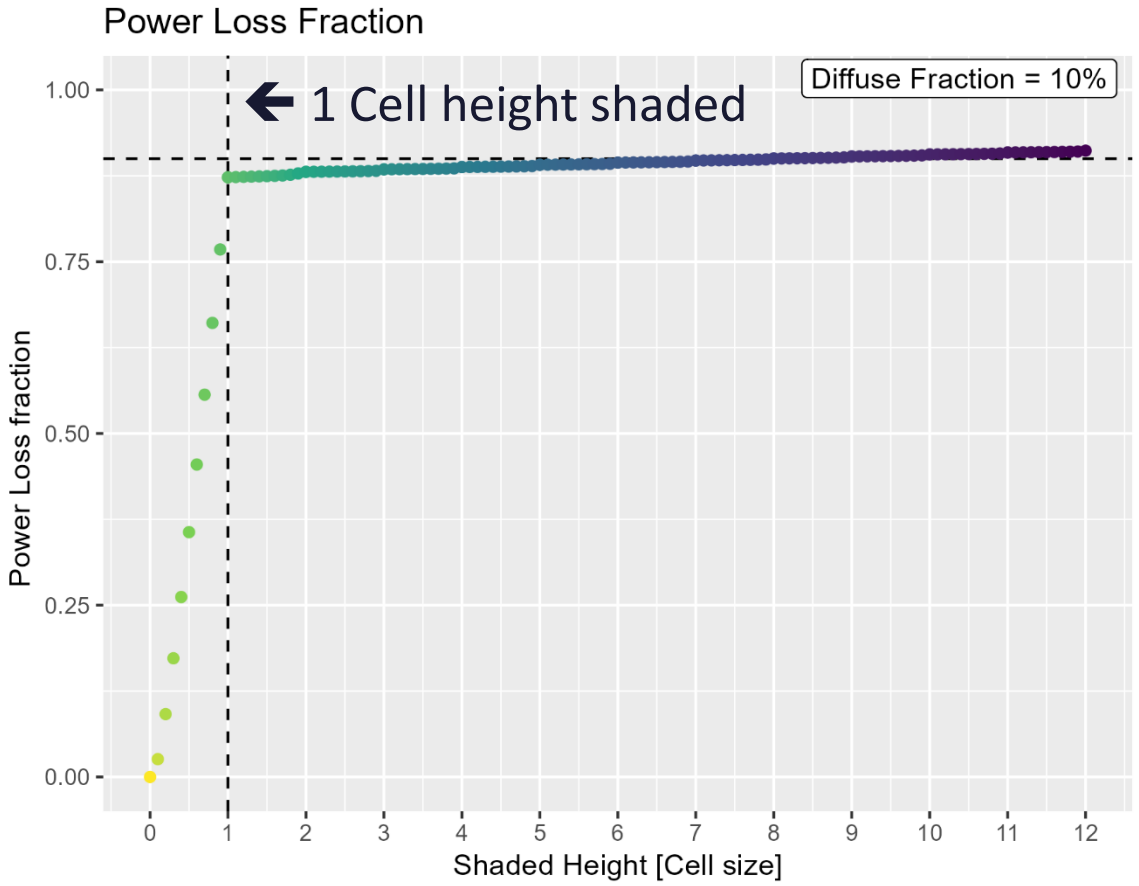
Example 1 : Normal Submodule

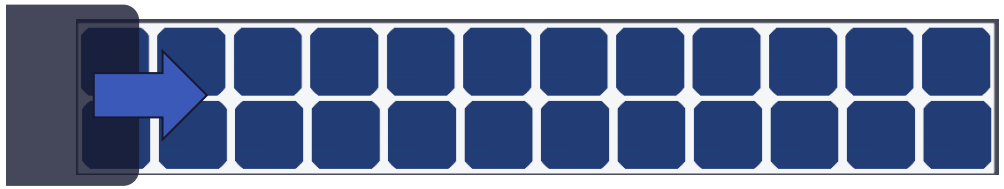


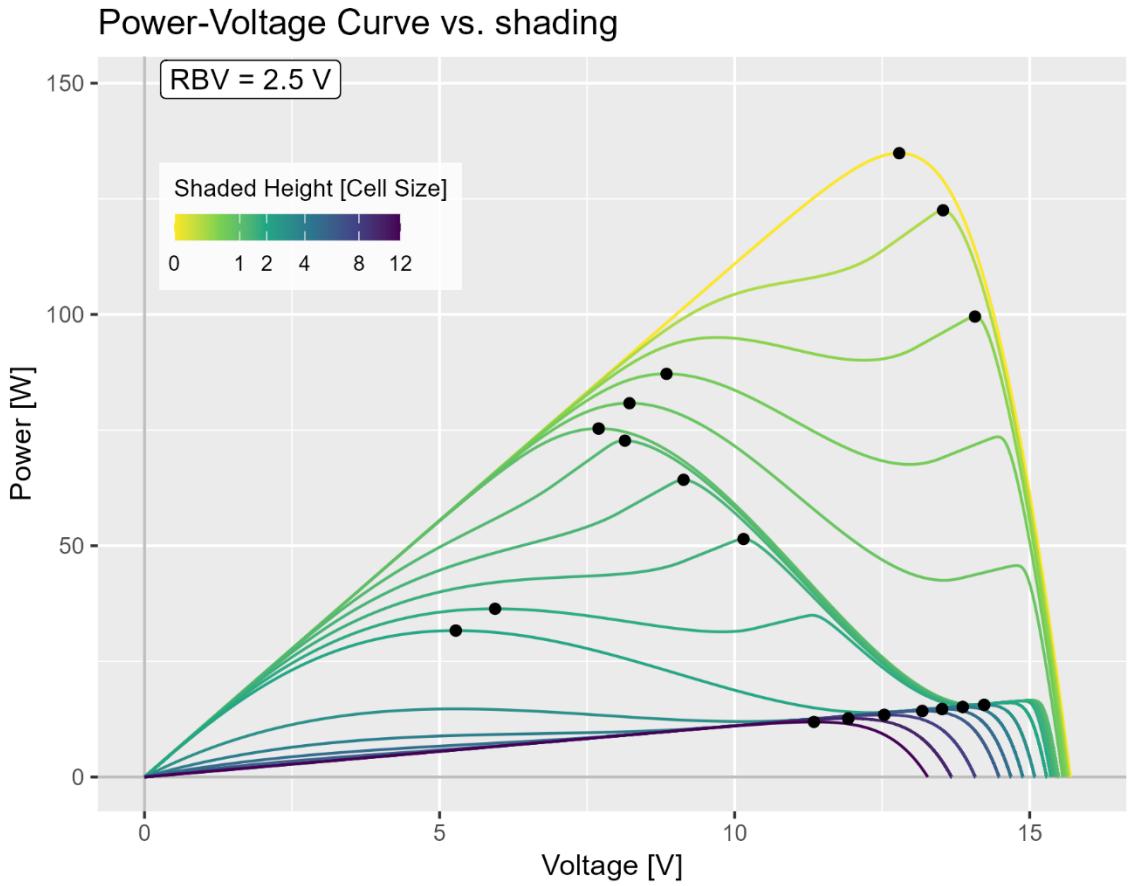


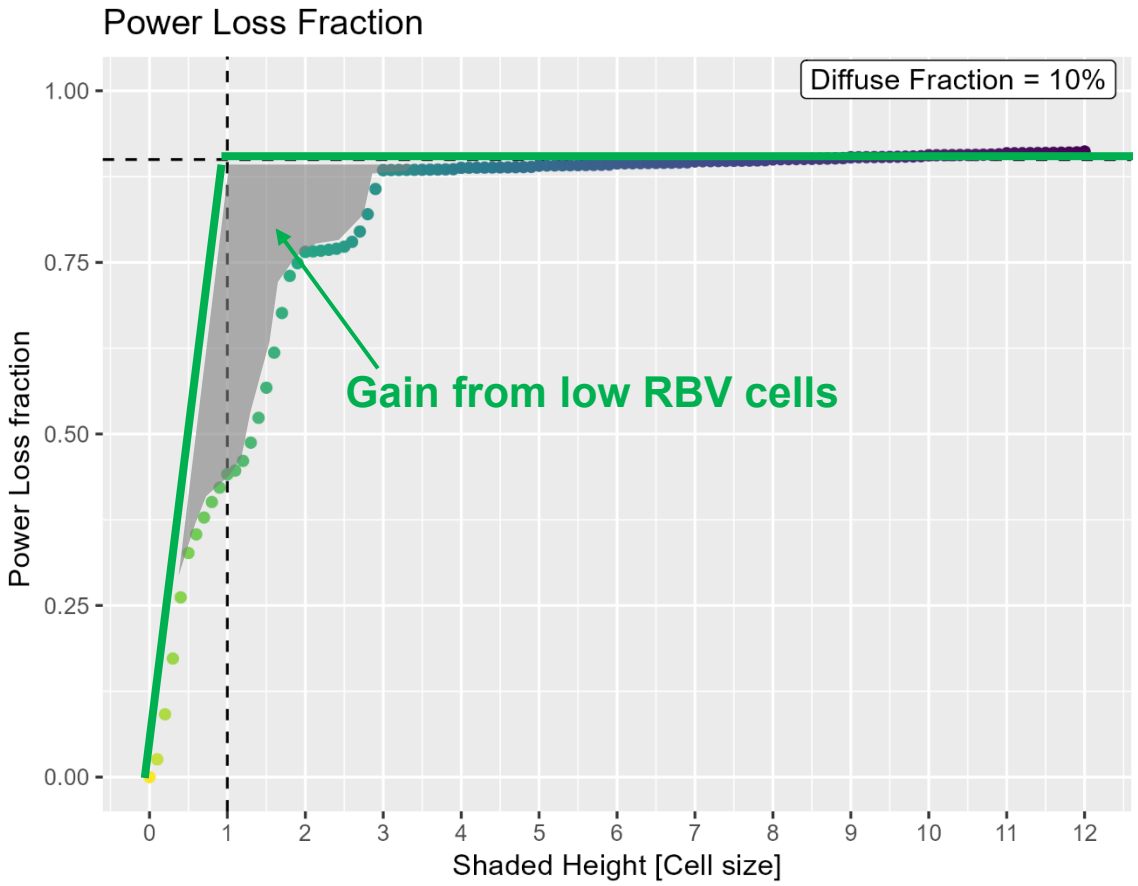


Loss Fraction well approximated by Plateau from 1 shaded row (i.e. two shaded 2 cells).

Example 2 : Low RBV Submodule







Shading mitigation from low RBV up to 2-3 shaded rows (4-6 cells)!
Note the large range of Vmpp.

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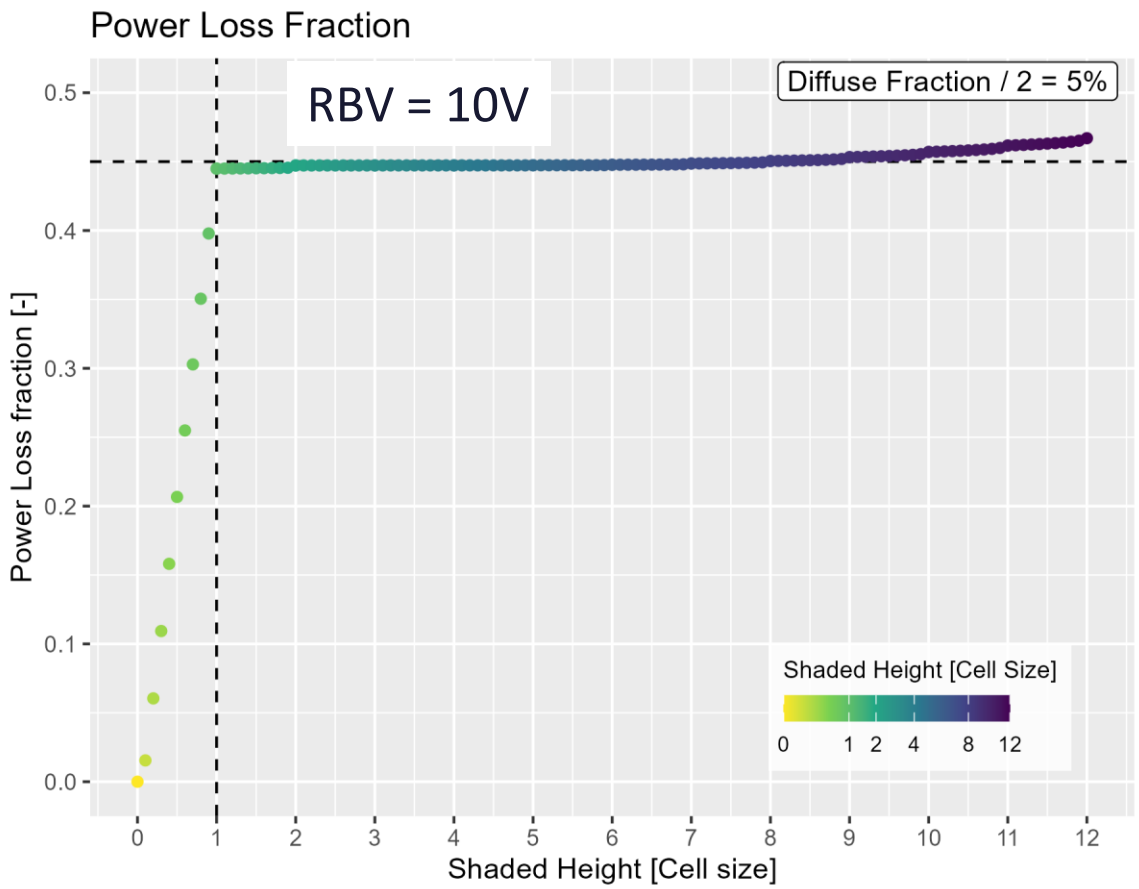
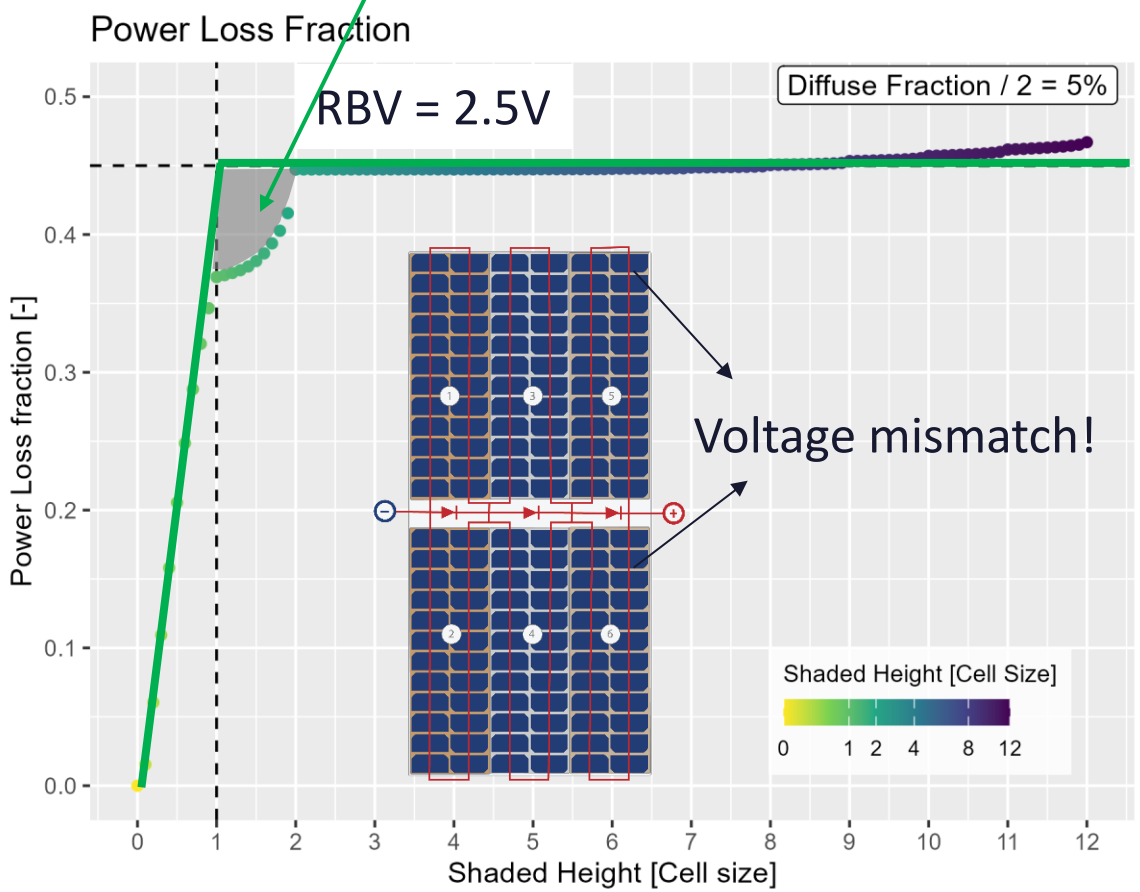
Example 3:
Low RVB Twin Half-cells submodules



Gain from low RBV cells much mitigated



Voltage mismatch! The top module pulls the voltage up ➔ interest of low RBV mitigated…
Converges to same plateau.

Near shading models in PVsyst

- Full I-V curves computationaly heavy for large system
- PVsyst «Partition model» mimicks well full I-V curves simulations for large regular system, featuring traditional modules. Definition:

Irradiance losses

Analytical (2D) or Polygon clip. (3D)

Beam → *Shd factor*

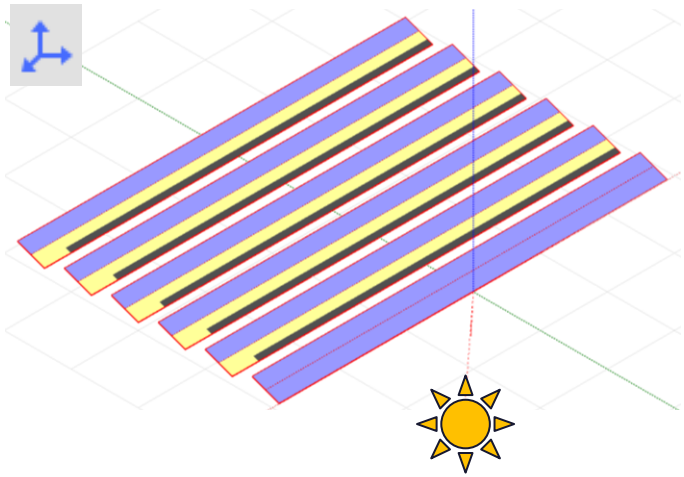
Circum. → *Shd factor*

Diff. → $\int_{Sky} \dots$

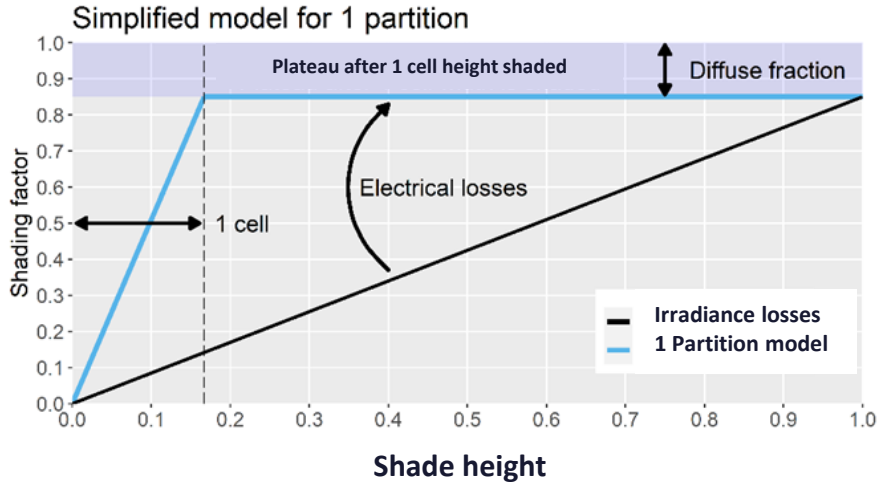
Albedo → $\int_{Ground} \dots$

Electrical losses

Separation of PV array in #N indep. partitions



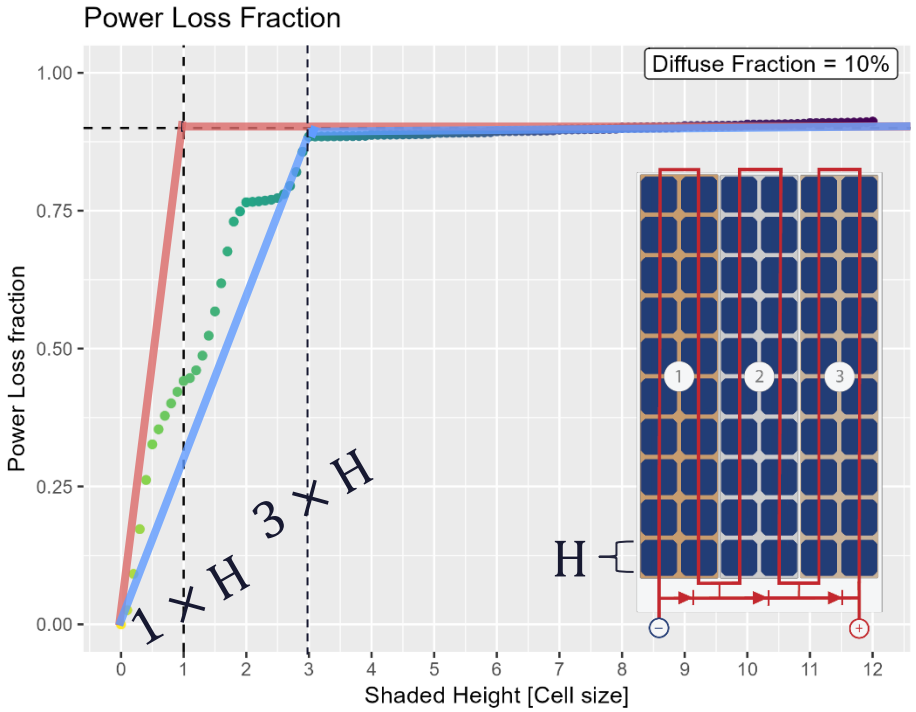
Associated loss factor to each partition => Plateau at one shaded cell.



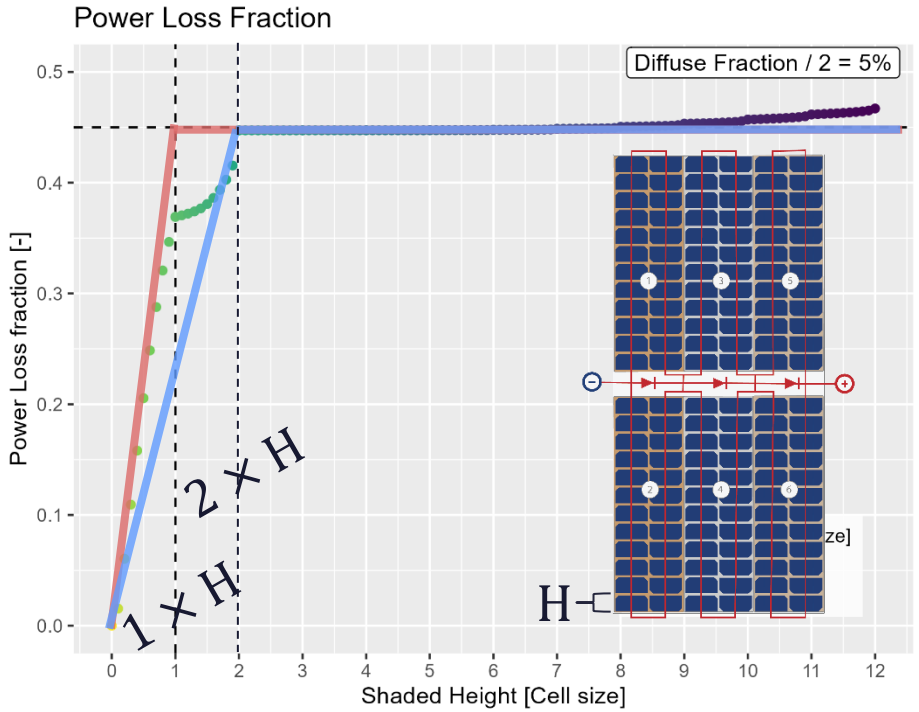
Question: Can the partition model be adapted to represent better low RBV cells?

Proposed adaptation of Partition model for low RBV (-2.5V)

«In length» module in portrait



«Twin half-cut» module in portrait



Classical partition model => Upper bound on losses

Optimistic adaptation for low RBV => Lower bound on losses

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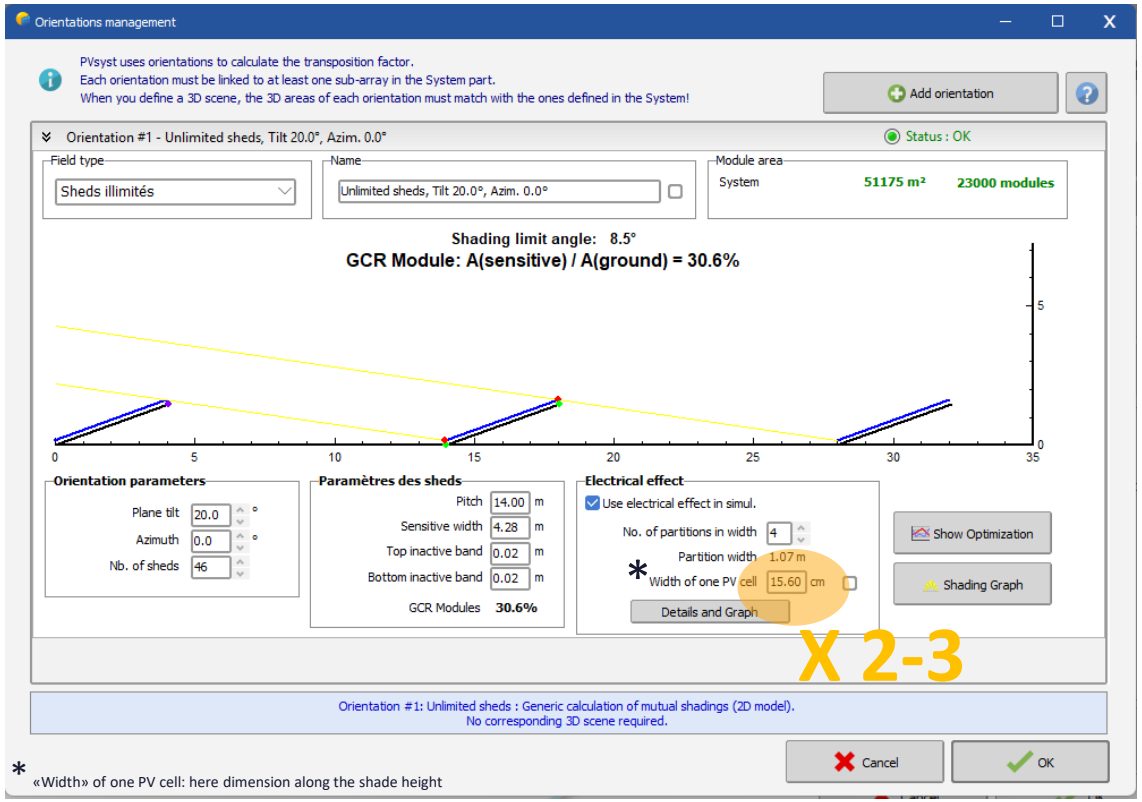
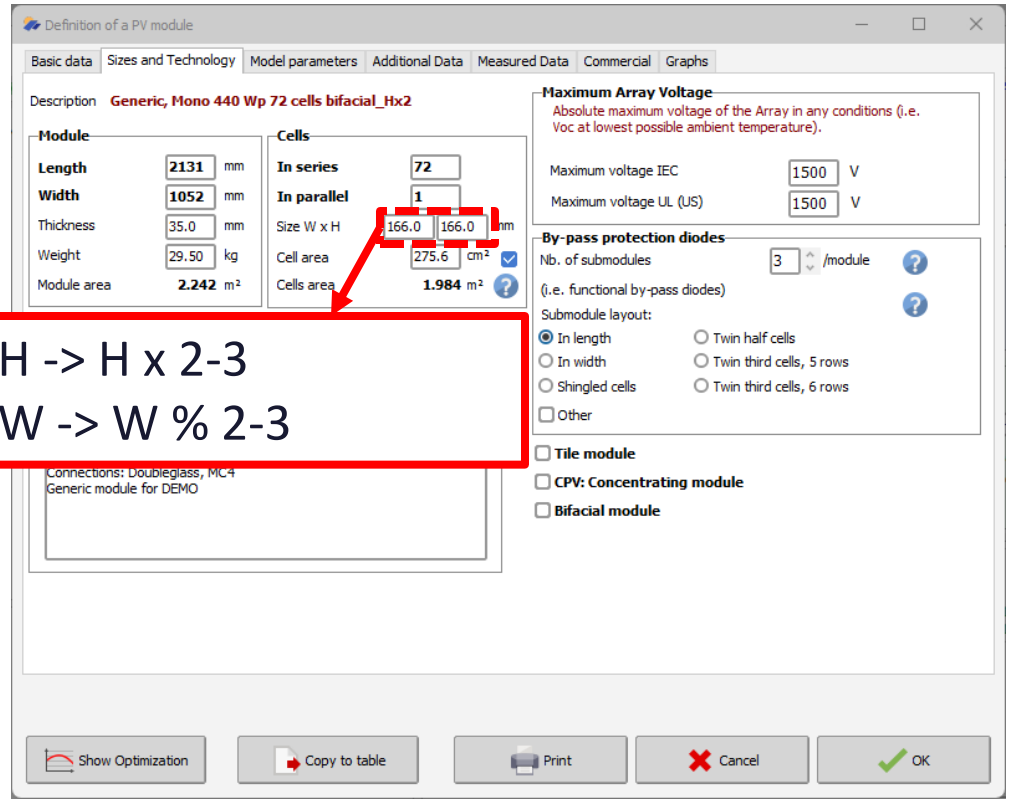
Possibility of Simulation in PVsyst

2D: «Unlimited sheds» or «Unlimited trackers»



- Easy to simulate quickly with "unlimited sheds" or "unlimited trackers" orientations,
- Input *2-3 times the cell size* to effectively represent a shading tolerant module with low RBV

3D scene with partition model: modify .PAN

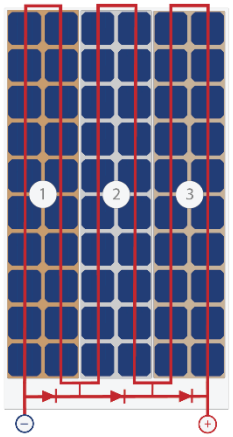


- Double or tripple H_{cell} (and halve by 2 or 3 W_{cell} to avoid warnings)

- **/!\ For validity, shadings needs to be as similar to "unlimited sheds" as possible!**

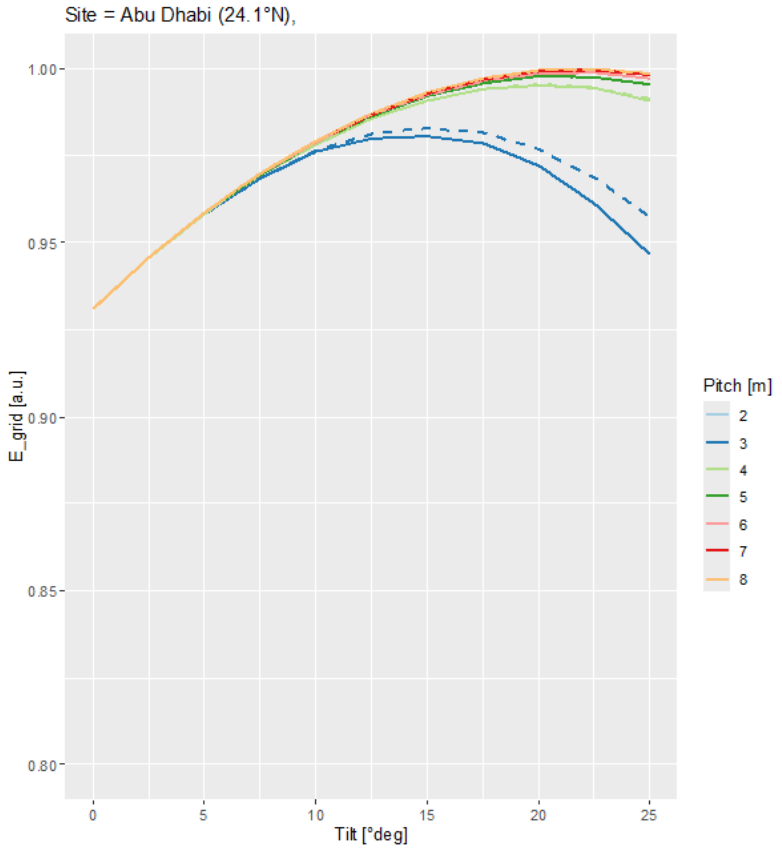
Example : Unlimited Sheds Simulation for limited Area

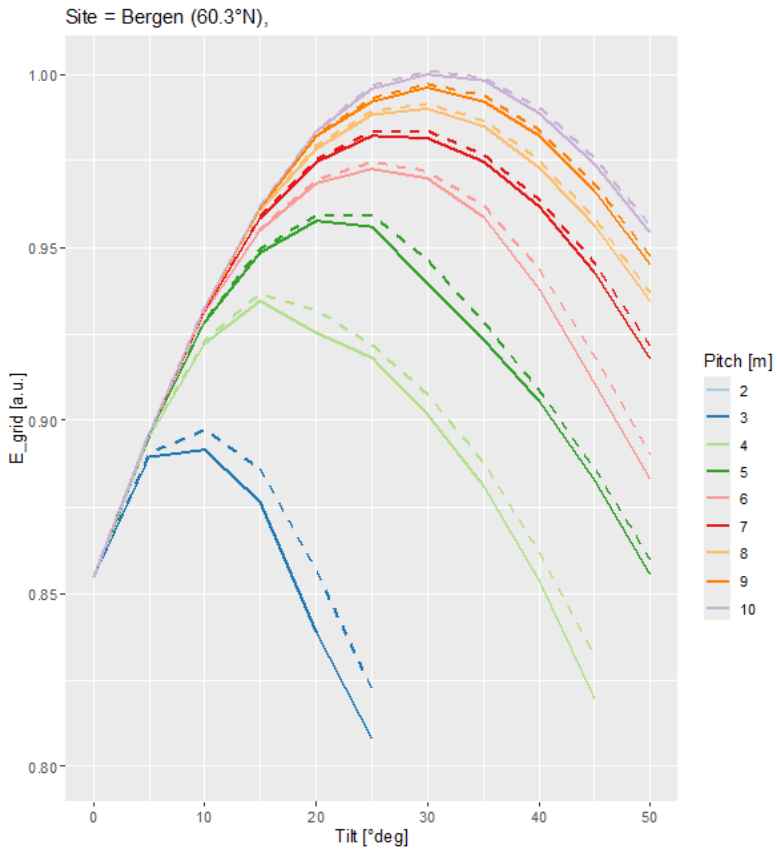
Optimization of Tilt and GCR



Hyptohesis favorable to low RBV technology:

1. *«In length» modules*
2. *Portrait*
3. *No parallel strings*
4. *Limited Area => increase shading*





Partition model
Cell Effective Width

1x width ➔ **No effect of RBV**

2x width ➔ **Slightly Optimistic RBV effect**

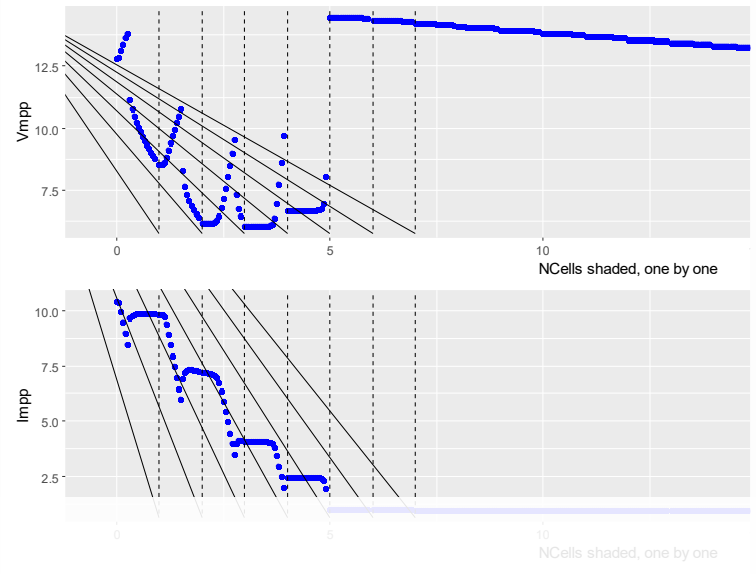
Very small gain for low RBV technology, more in northern latitude and limited area.

Open questions

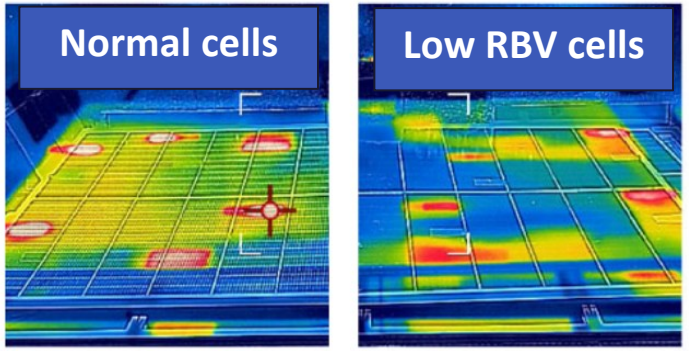
1) More complexe shadings scenarios to explore

Image @Aiko

2) Peculiar MPPTs tracking?



3) Hot spot reduction of interests for reliability



Tang, 10.1038/s41467-026-70005-1

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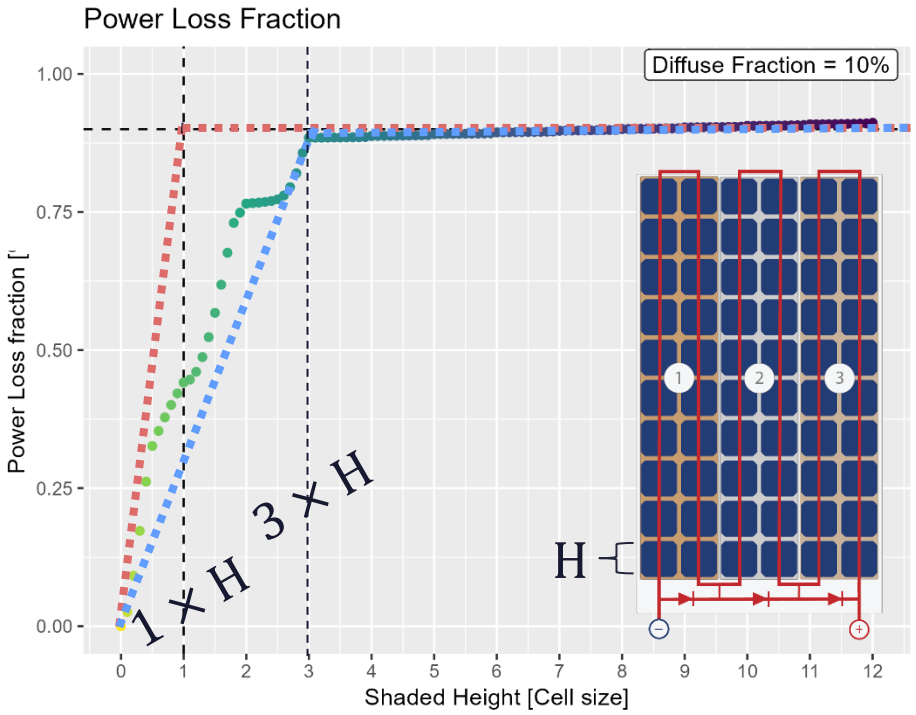
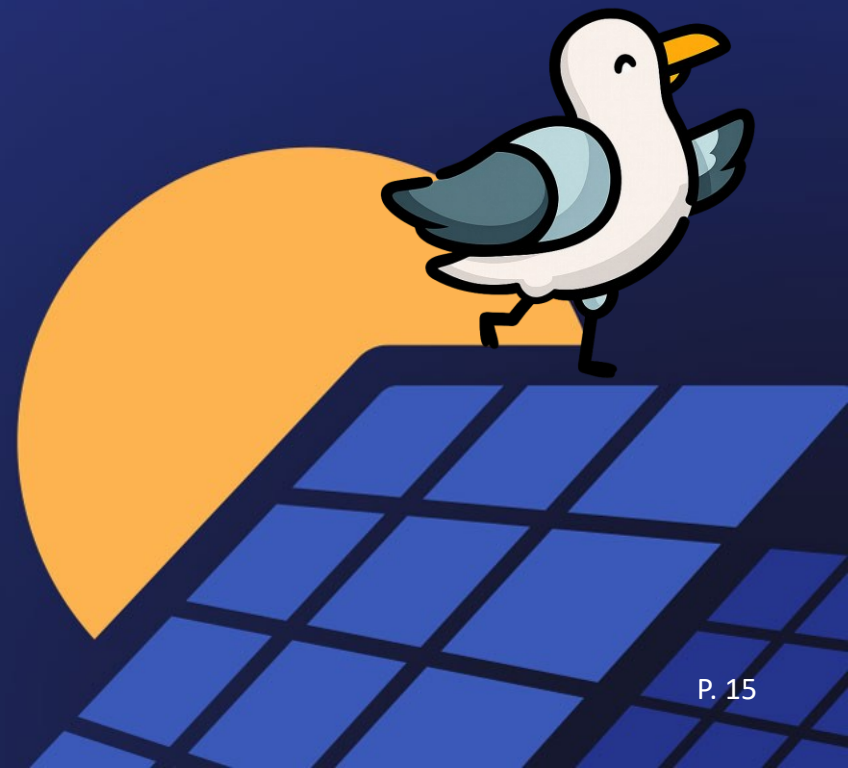
Conclusions

1. Low-RBV BC cells (-5 V to -2.5 V) provide only modest energy-yield gains.
2. They differ from standard PV modules only when fewer than 4 cells are shaded
3. Portrait “in-length” low-RBV modules can be approximate in PVsyst doubling the effective cell size in the partition model.
4. Benefits are quickly reduced by voltage mismatch when unshaded (sub)-modules are connected in parallel, e.g.
    1. Standard modules in landscape
    2. Twin half-cut /!\
    3. Parallel strings
5. More complex localized shading scenarios require more analysis.

Partition model modification for «In length» module



Thank you for your attention



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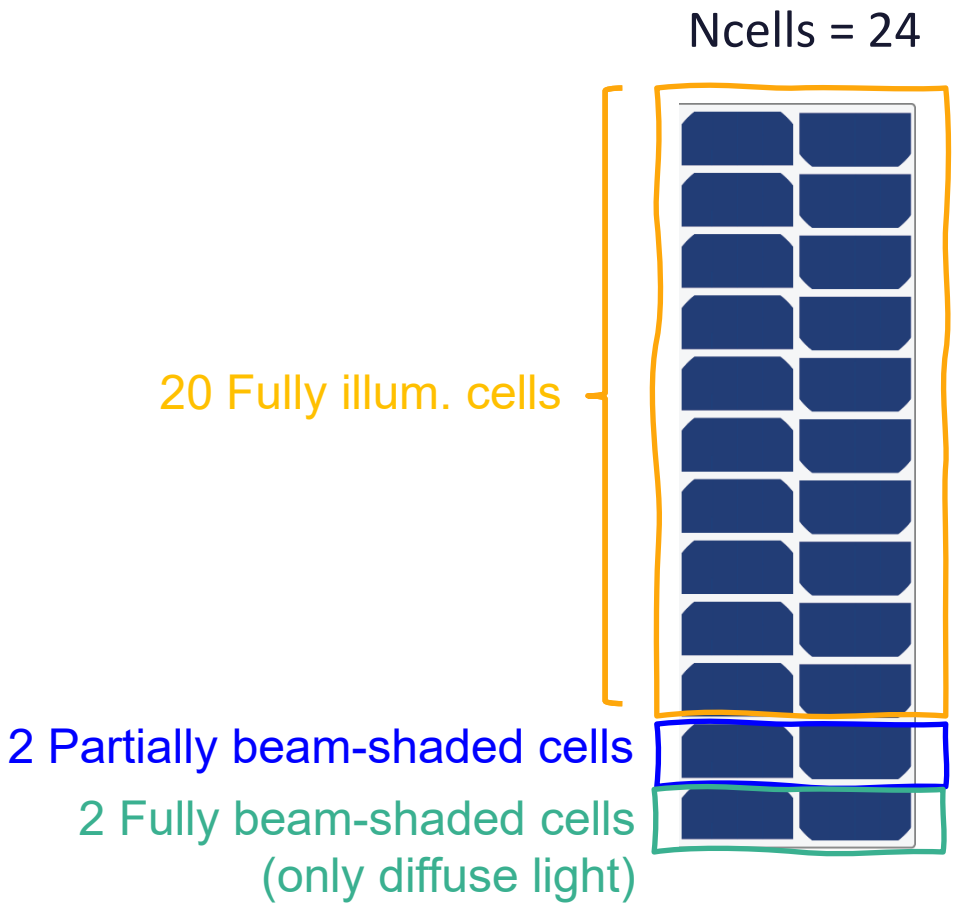
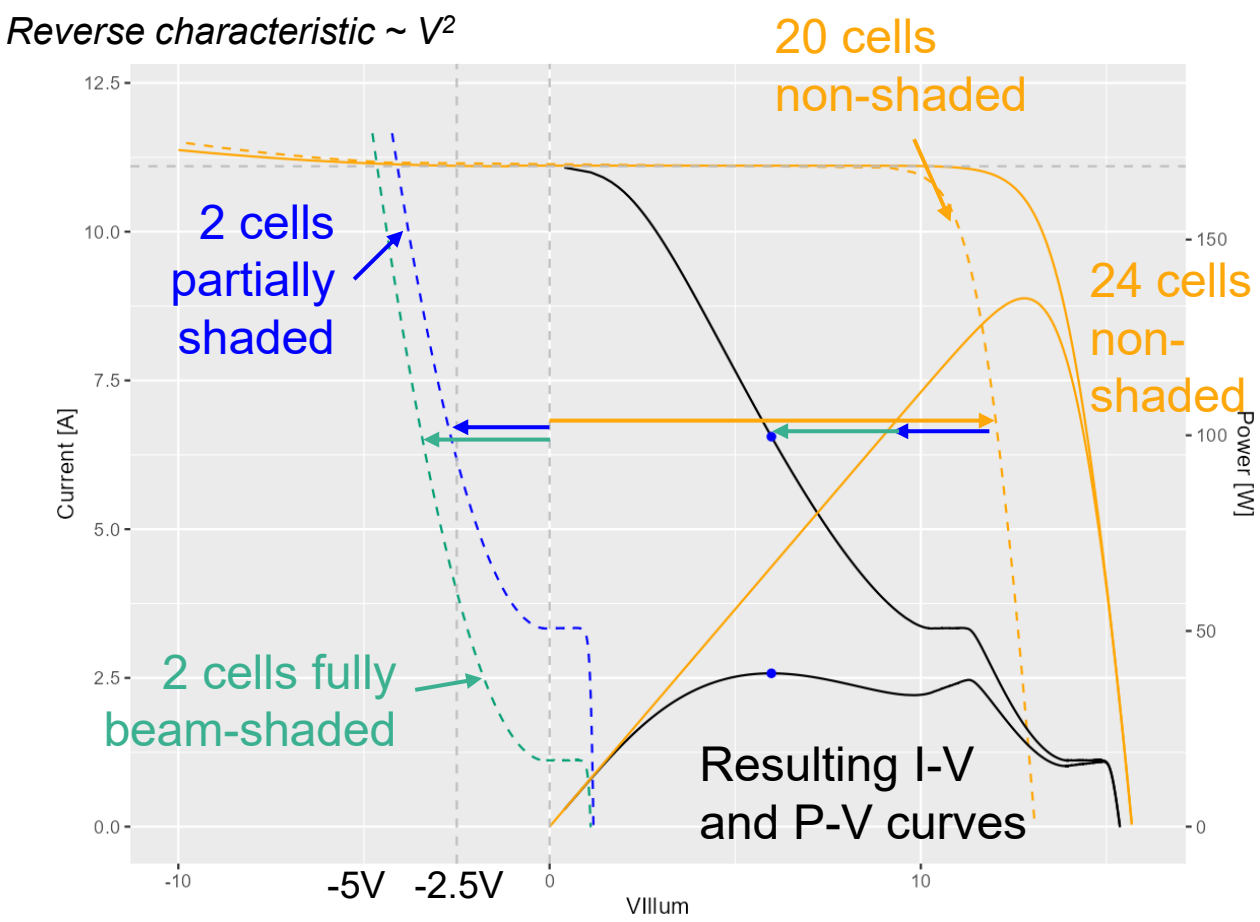
Bonus slides

Submodule IV curve of low RBV cells





Exact I-V curve constructions unveils complex properties

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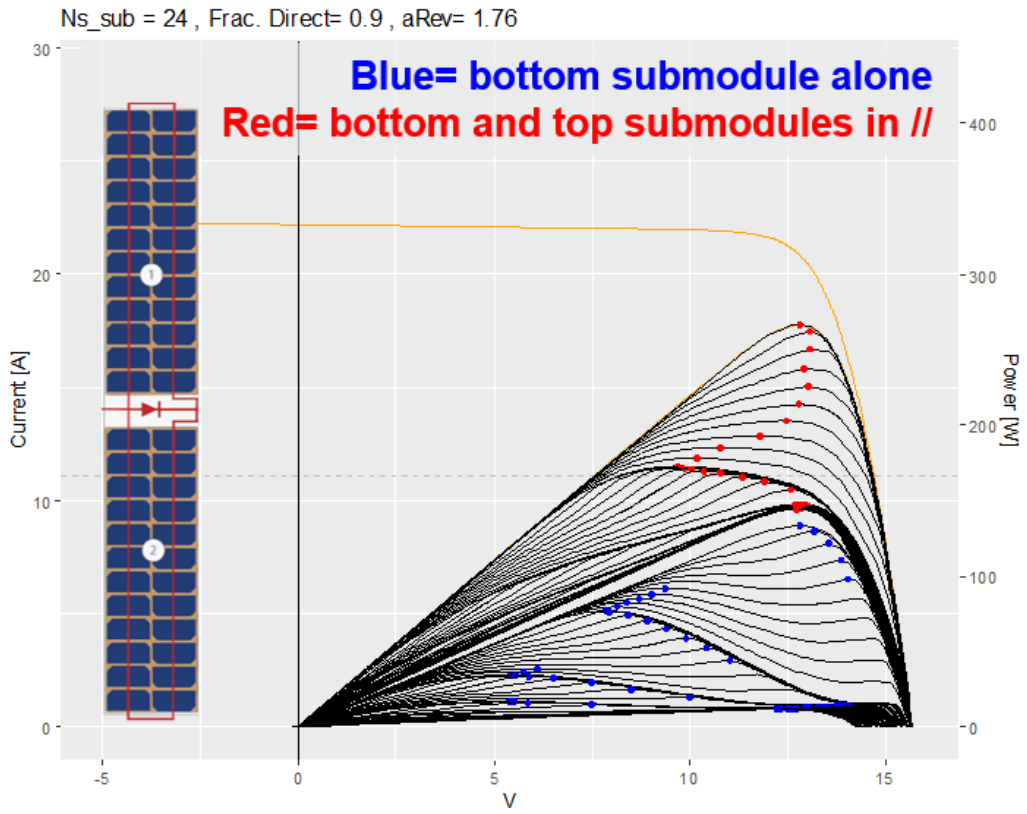
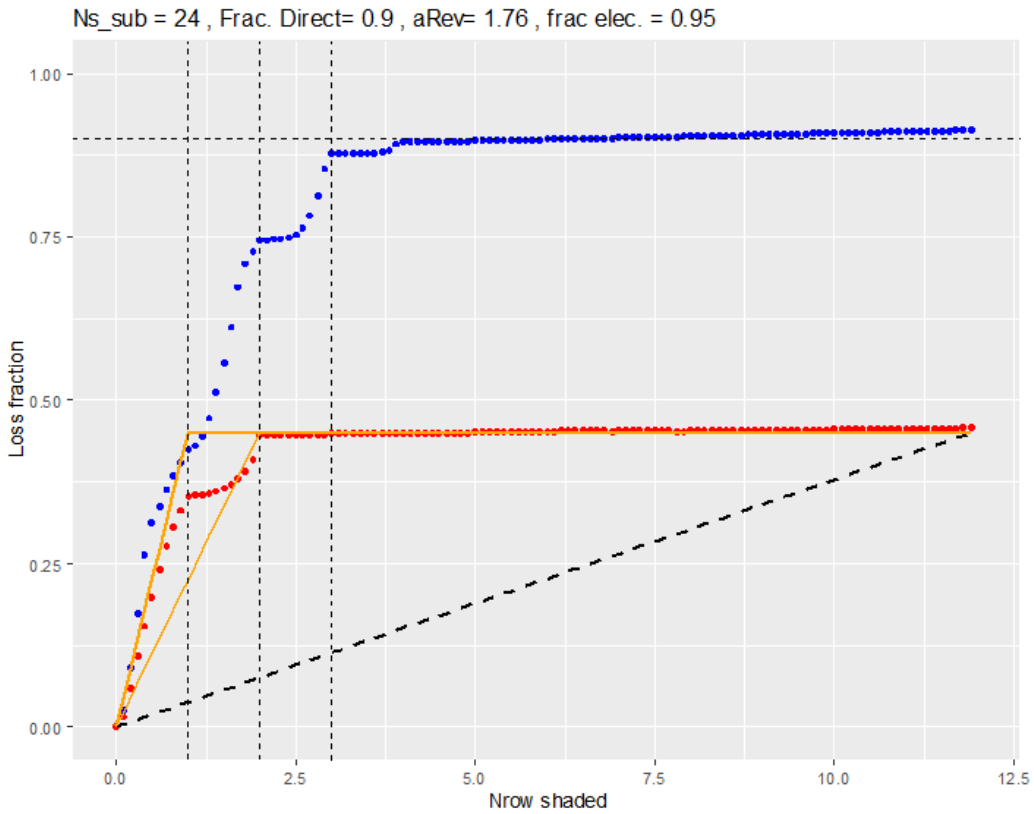
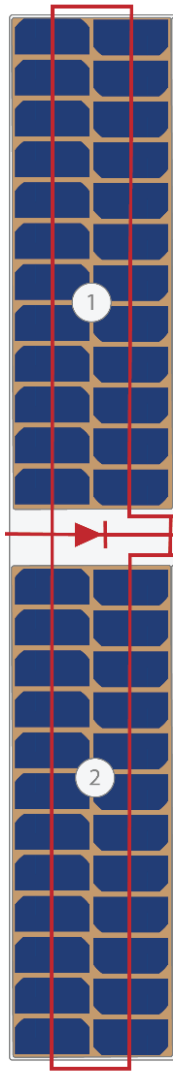
Example 3:
Low RVB Twin Half-cells submodules

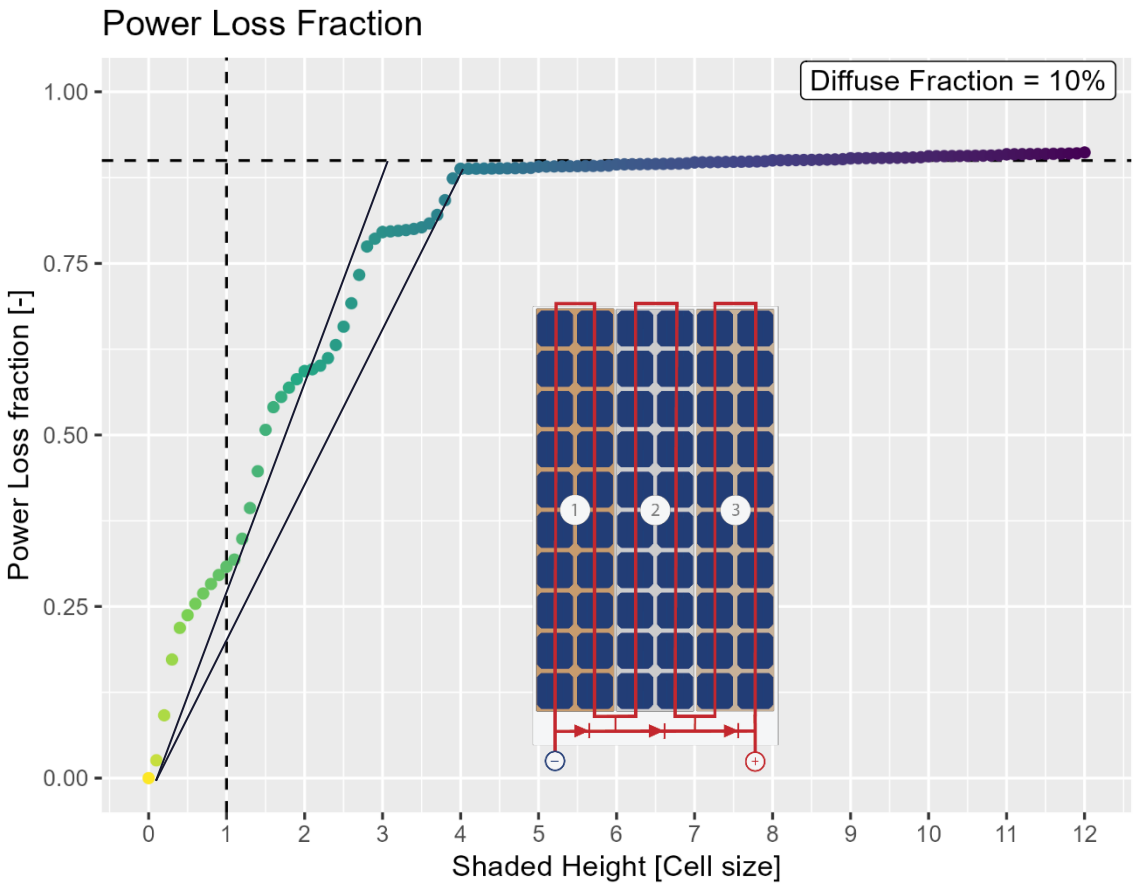


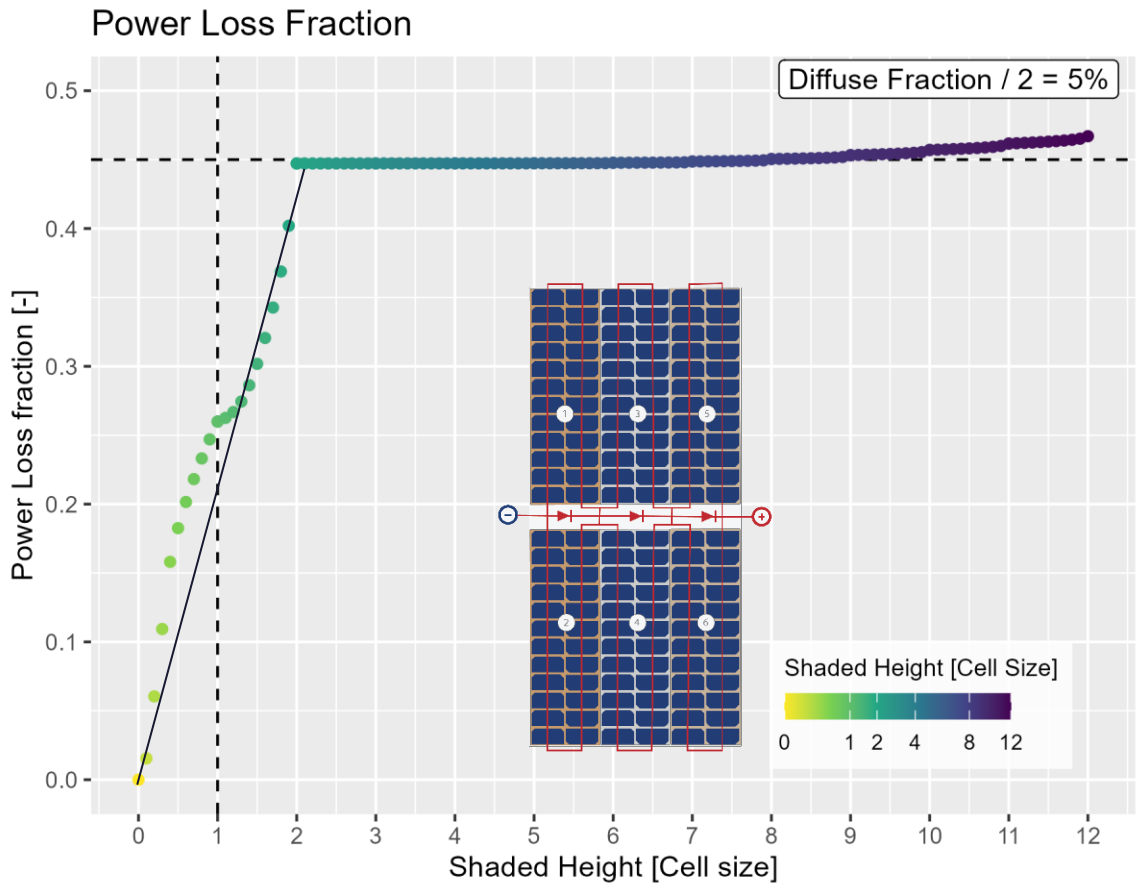




Voltage mismatch! The top module pulls the voltage up ➔ interest of low RBV mitigated…
Above converges to same plateau.

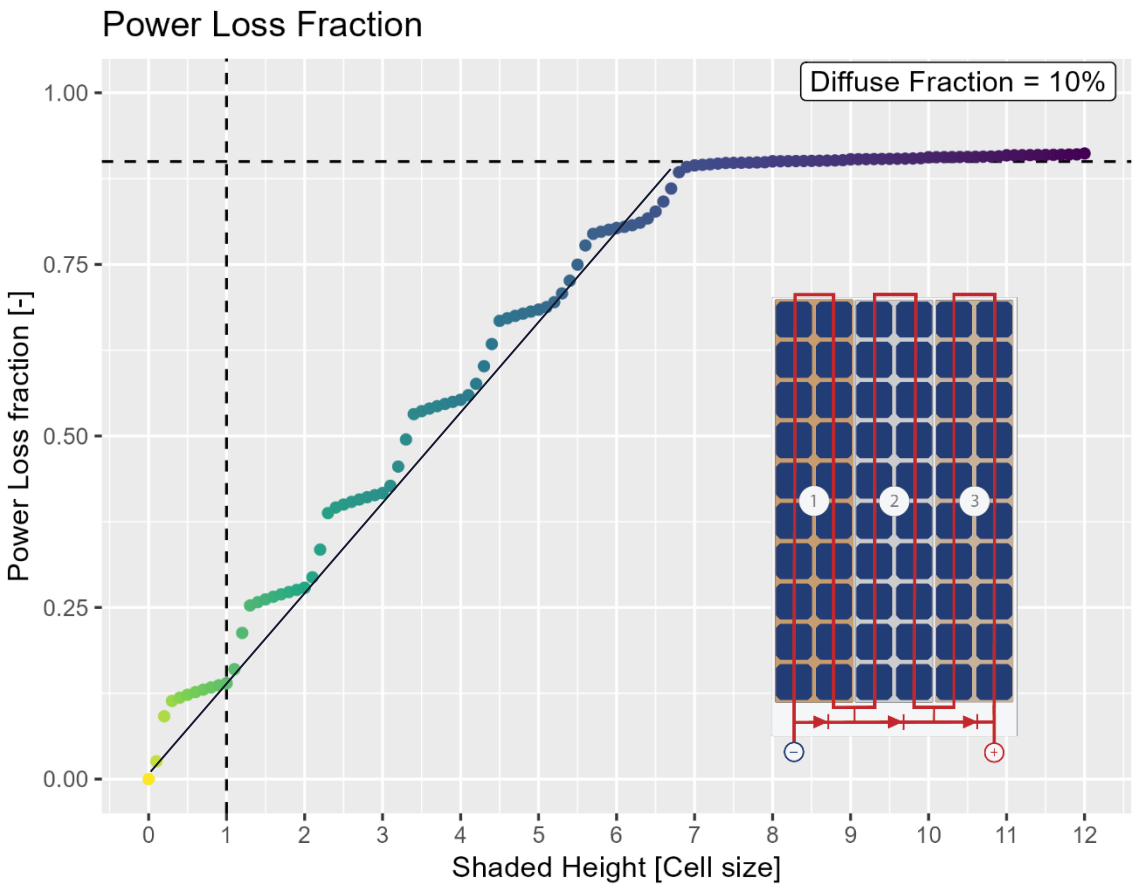
Example 4 : extra Low RVB Submodule (RBV = 1.5V)

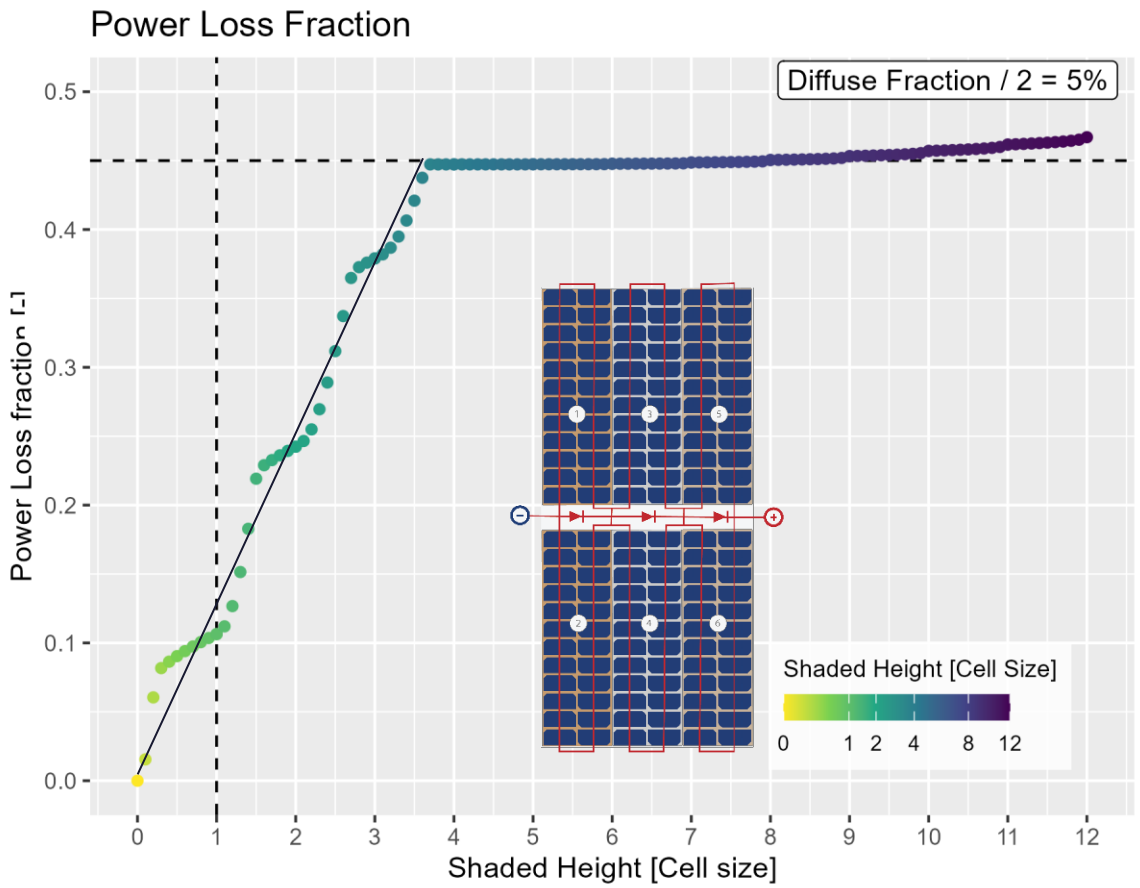




Note: Those values have not been demonstrated in practice yet in commercial cells

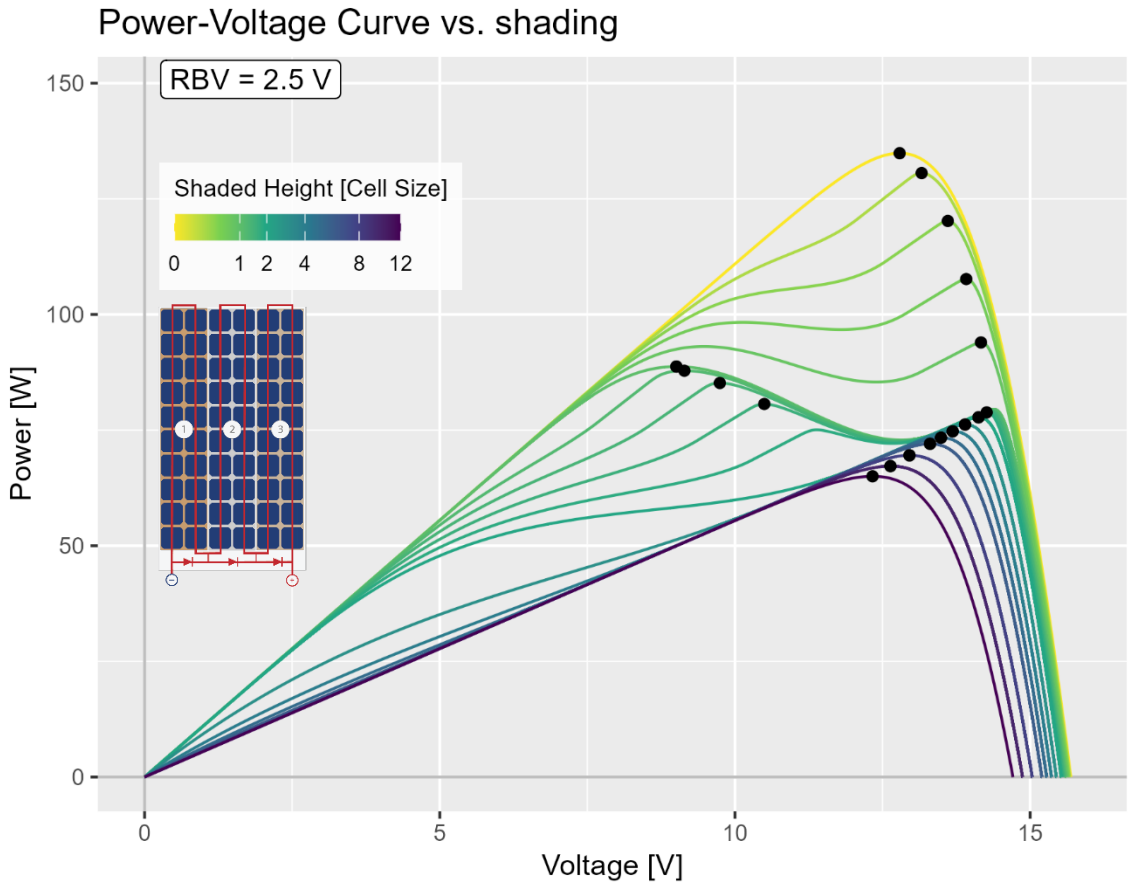
Example 5 : extra-ultra Low RVB Submodule (RBV = 0.3V)

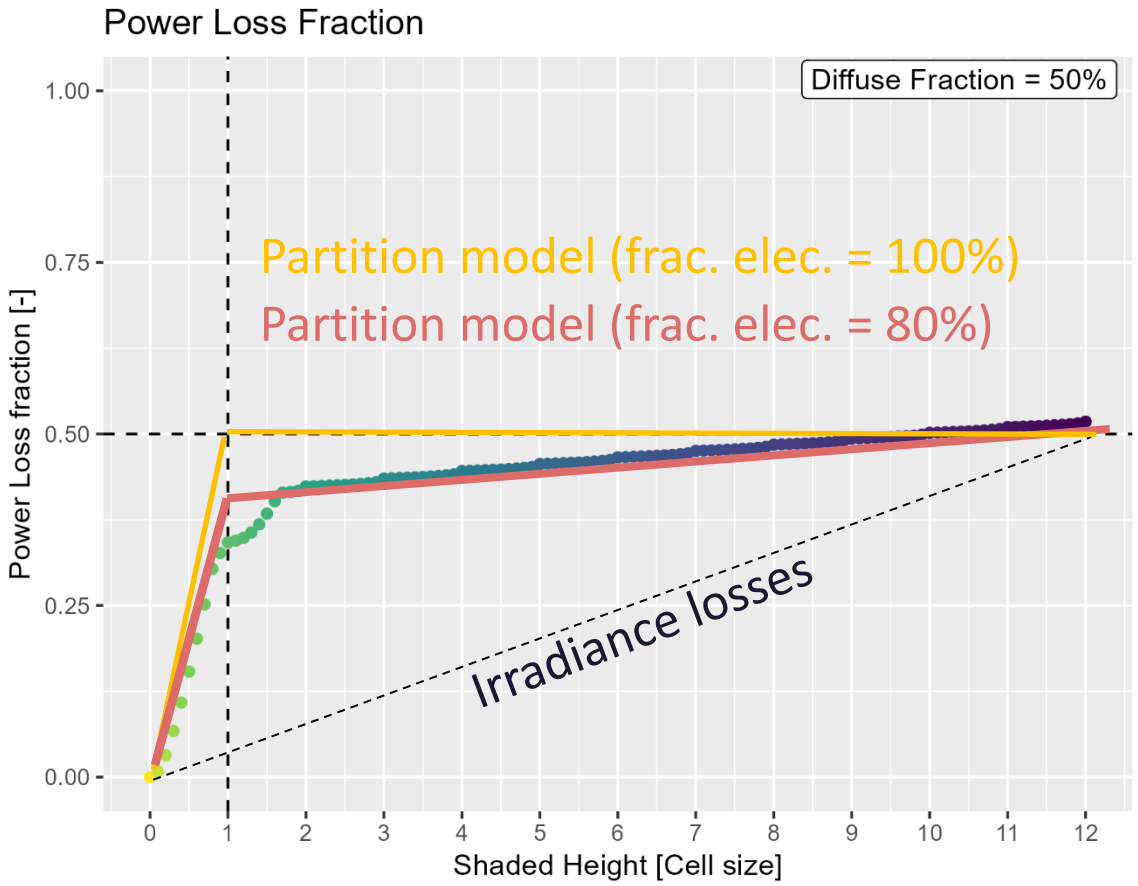




Note: Those values have not been demonstrated in practice yet in commercial cells

Example 6 : Low RVB Submodule (RBV = 2.5V) and high diff. Frac (50%)





Cloudy Day reduce the interest for low RBV cells.
Adapting the electrical fraction parameter of PVsyt to better model cloudy day.
The parameter needs to be tuned to find the relevant annual results!

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