Shading Calculation in PV*SOL Expert

- *Horizon, Near and Inter Row Shading*
- *Method of Calculation*
- *PV Module Model*

Bernhard Gatzka

Valentin Software, Germany

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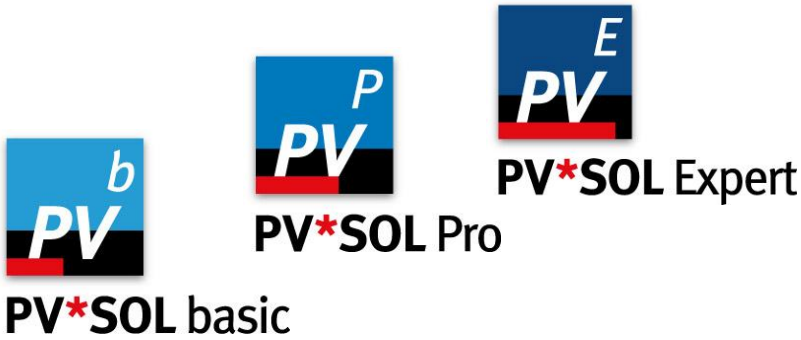
Company Overview

- **Software Development of Design, Simulation and Modeling tools for Photovoltaic and Solar Heating Systems**
- **Established 1988**
- **40 employees (of which over 50% are engineers and developers)**

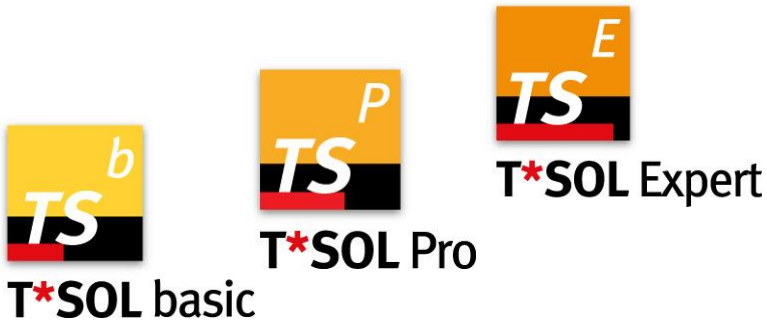
Global Headquarters:
Dr. Valentin EnergieSoftware GmbH
Berlin, Germany
www.valentin.de

North American Headquarters:
Valentin Software, Inc.
Temecula, CA
www.valentin-software.com
info@valentin-software.com

Standard Software Families



A dynamic simulation program for the **design and calculation of photovoltaic systems**, including grid-connected, off-grid and battery backed-up systems.



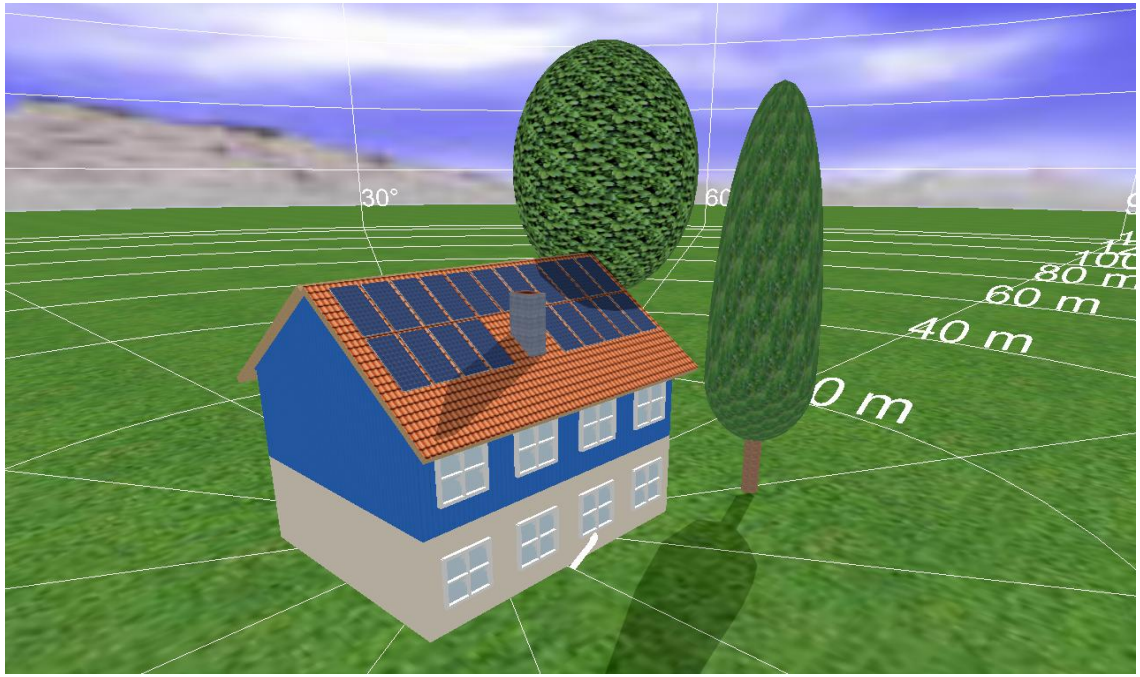
A dynamic simulation program for the **design and optimization of solar thermal systems**, for applications including space heating, domestic hot water, pools and industrial usage.

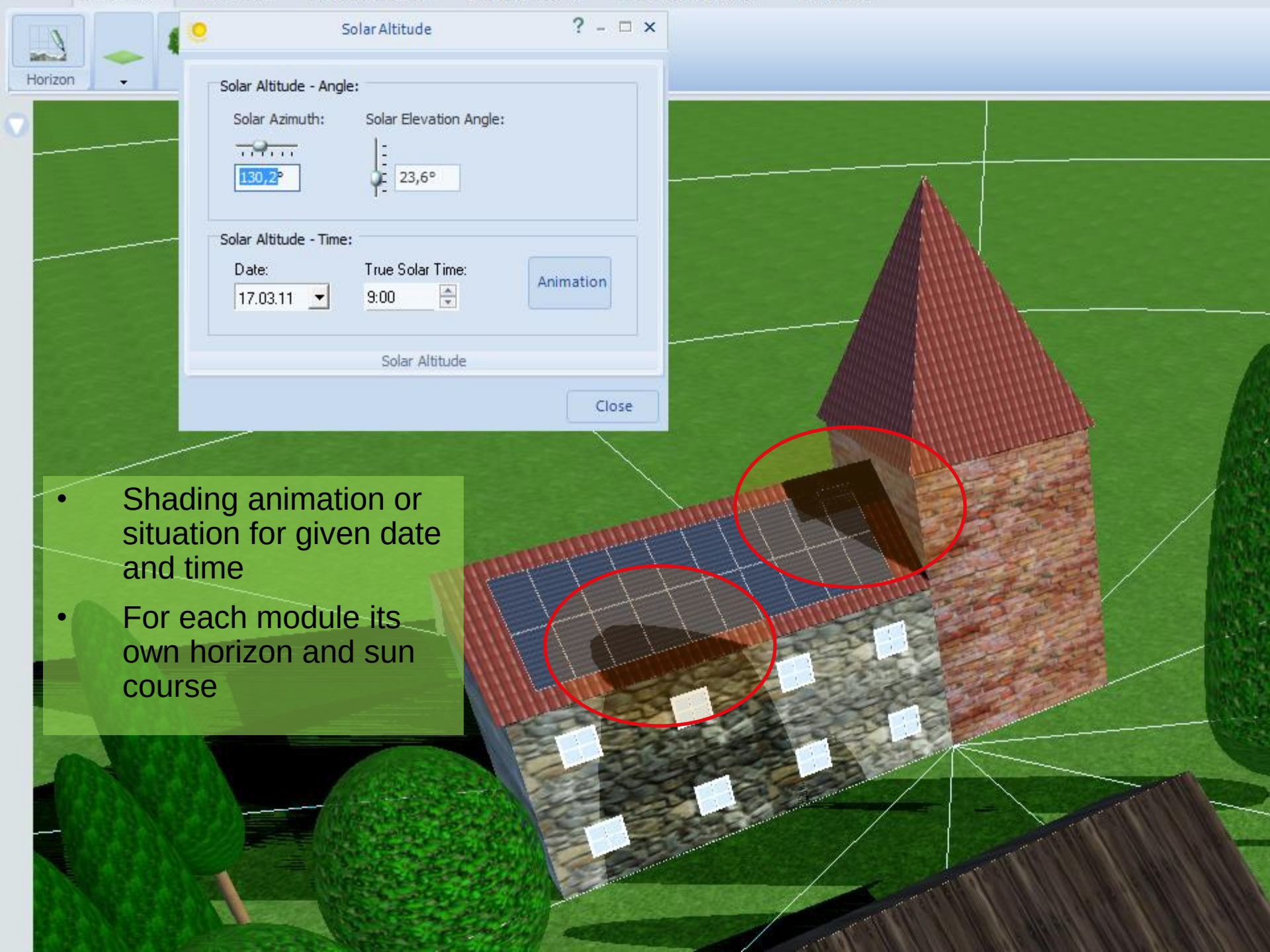
Agenda

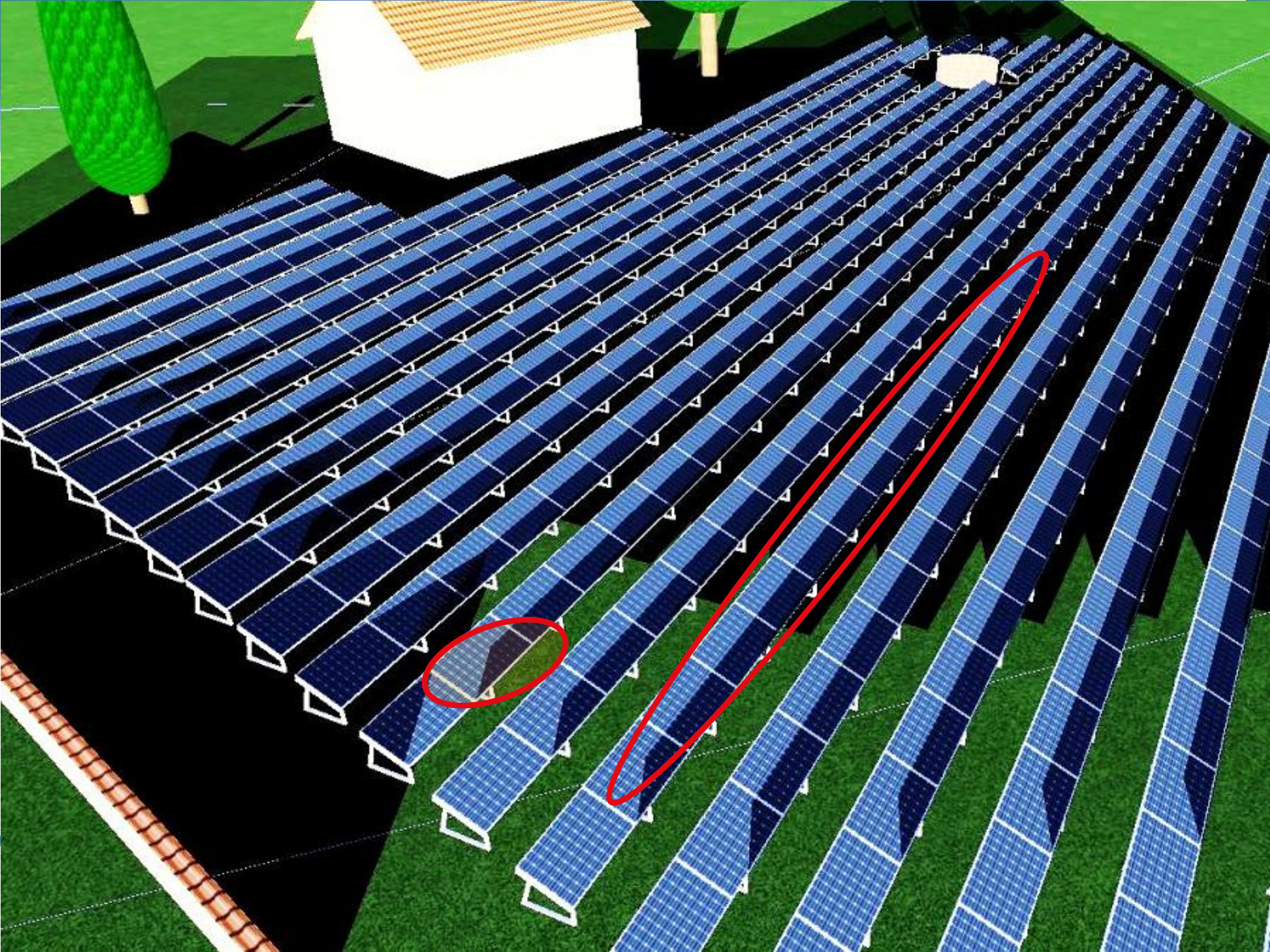
- Company Overview
- 3D Visualization
- Calculation of PV array
- PV*SOL Module Model

PV*SOL Expert

3D Visualization plus all the capabilities and features of PV*SOL Pro




Horizon
Solar Altitude
Solar Altitude - Angle:
Solar Azimuth:
Solar Elevation Angle:
130,2°
23,6°
Solar Altitude - Time:
Date:
True Solar Time:
17.03.11
9:00
Animation
Solar Altitude
Close
• Shading animation or situation for given date and time
• For each module its own horizon and sun course



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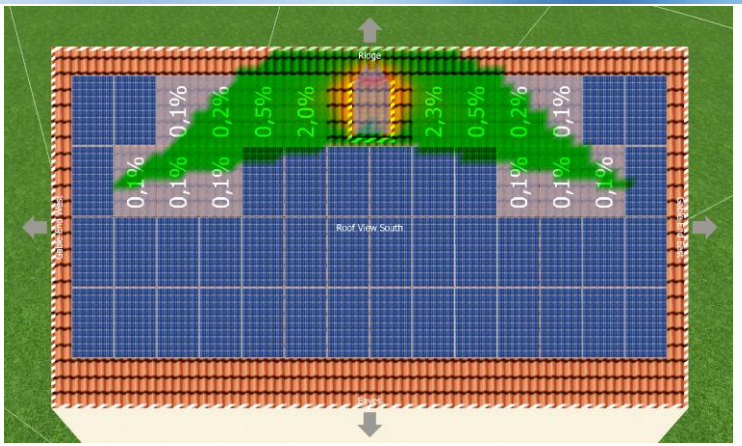
Calculation of PV Array

Shading analysis helps defining the strings.

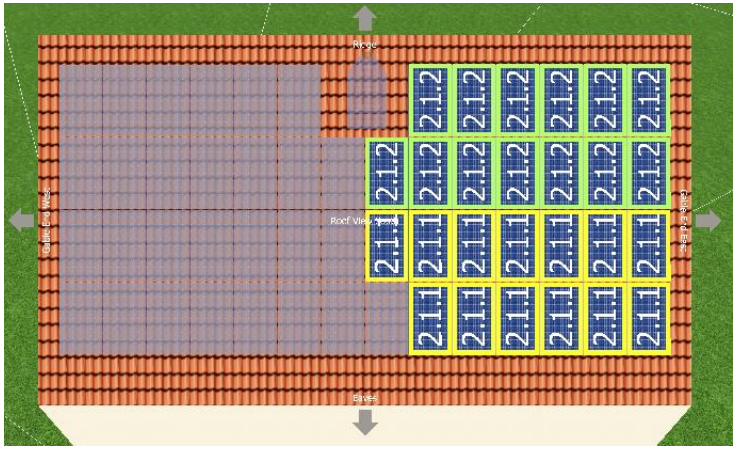
Each MPP tracker defines an array.

At each time step the following steps are done :

- Calculation of IV-Curves depending on irradiation, temperature and shadow situtation
  - For each module
  - For each string
  - For the array
- Determination of the point of maximal power in the I-V-Curves of the array



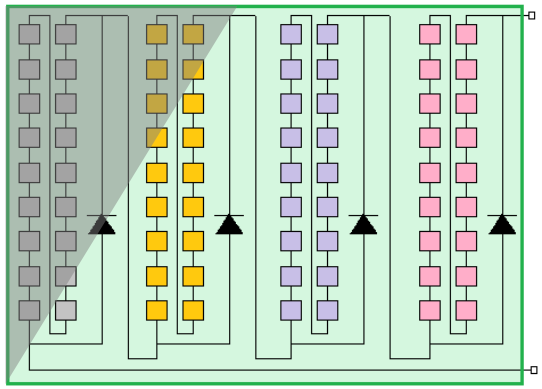
Reduction of radiation for each module (direct & diffus)

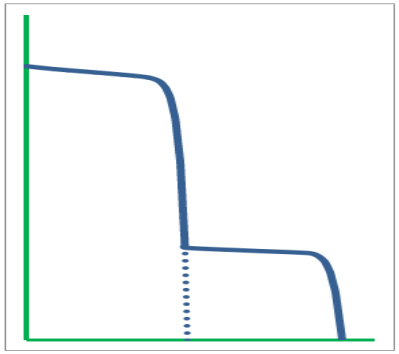


2 MPP tracker with 2 strings each

Module Substrings

- Bypass diodes split the module to serial substrings. The count of diodes defines the count of substrings.
- A substring is regarded as fully shaded if the shade line cuts the substring area.
- Shaded cells get the diffuse radiation only.
- Substrings can get parameterized as horizontal or vertical. Important in case of inter row shading.
- Example:
  I-V-Curve
  of half shaded
  module

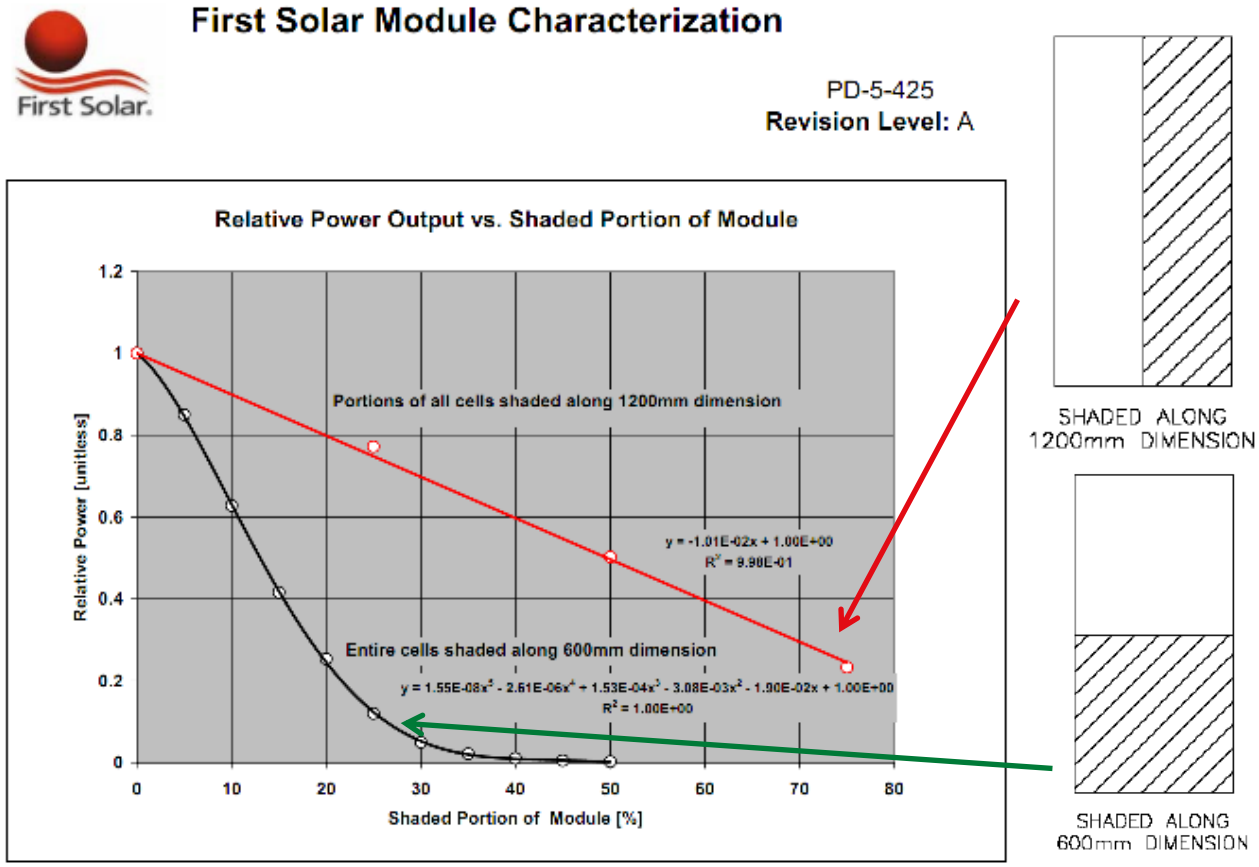




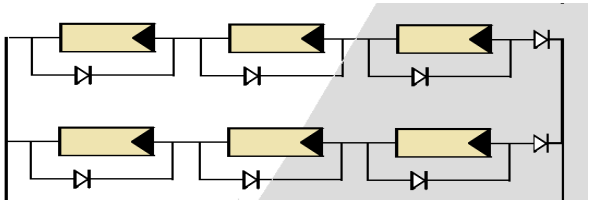
Thin Film Modules

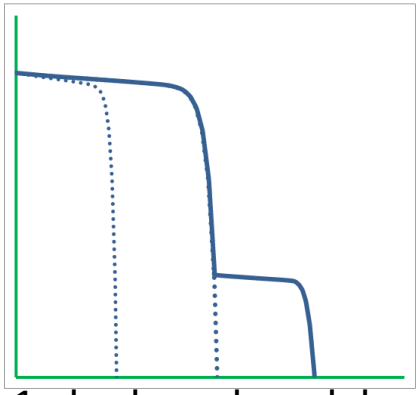
Source: First Solar Documentation
PD_5_425_Module_Characterization_Module_Shading.pdf

- Partial shading of all stripes reduces linearly.
- Shading of complete stripes reduces disproportionately.
- PV-modules based on thin film cell stipes were calculated as shown in the diagram!

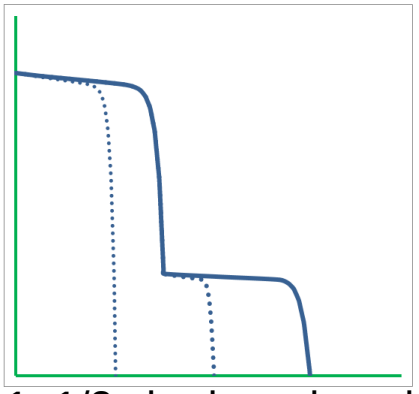


Shadowed Array



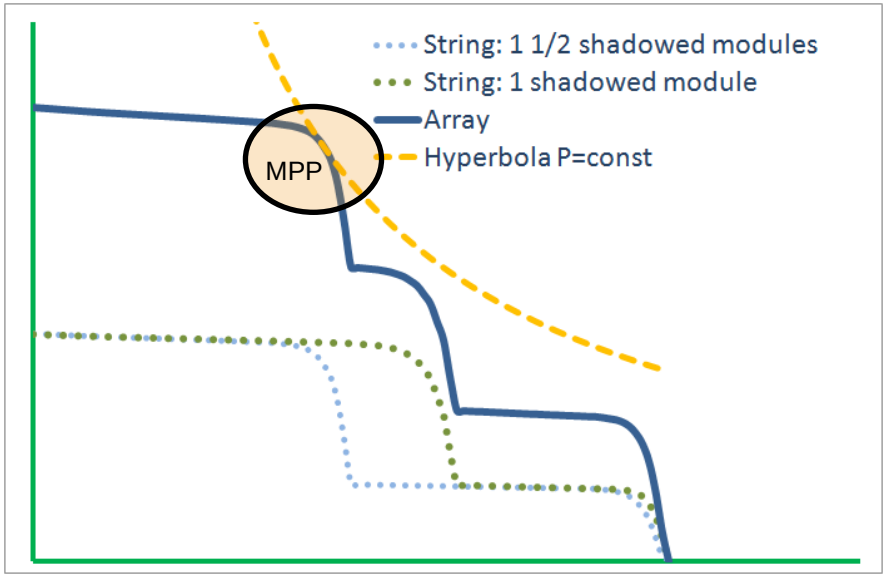


1 shadowed module



1+1/2 shadowed module

- String:
  For each current addition of voltages
- Parallel Strings:
  For each voltage addition of currents
- Find the best point of maximum power



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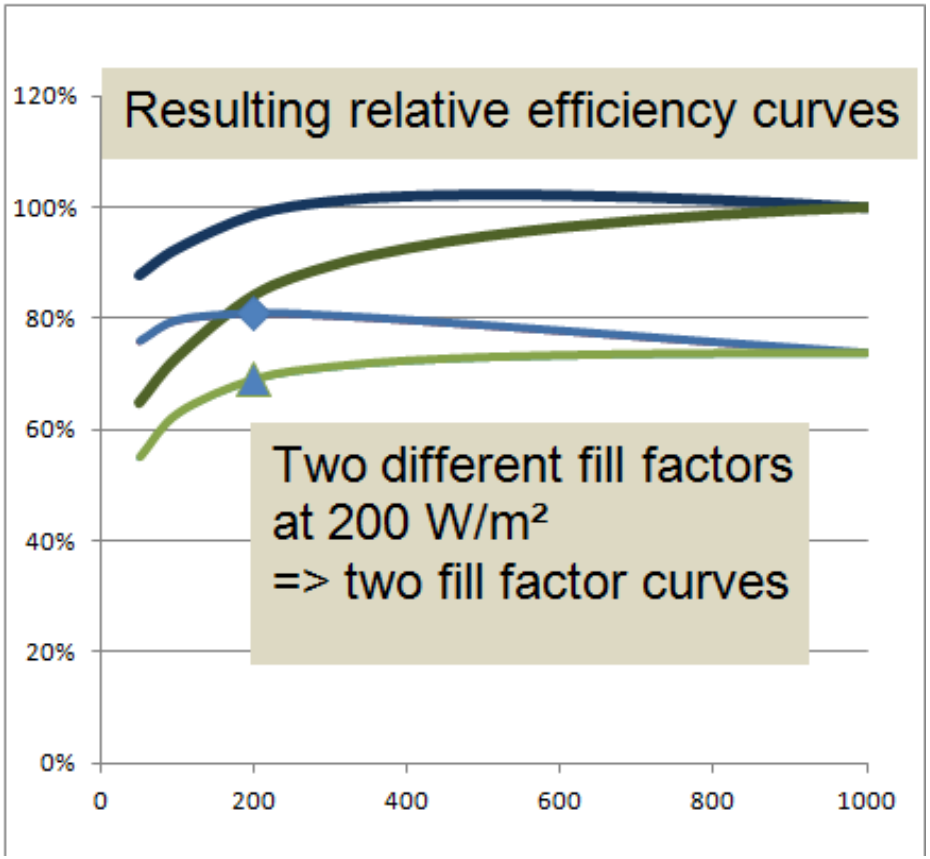
Model Requirements

- Valid on MPP and for arbitrary voltage values (I-V Curves)
- Based on data sheet (working points at STC)
- Fast calculation algorithms
  - So far the One-Diode-Model succeeds.
- + Tunable „Low Radiation Efficiency“
- => Valentin‘s Model Extension:

  Extra Working Points at an arbitrary radiation

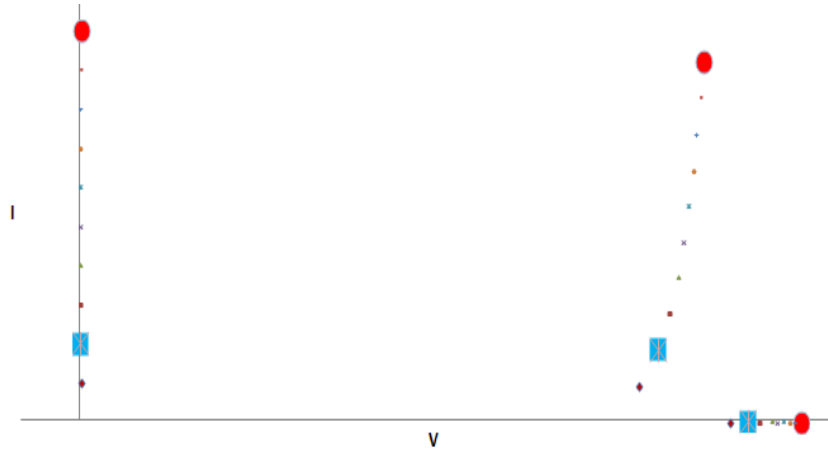
Efficiency Dependency on Radiation

- Needed data: $G_{low\ rad}$, U_{OC}, U_{MPP} , I_{MPP} , I_{SC}
- This defines: Fill factor at $G_{low\ rad}$
- Approach for fill factor dependency:
  $FF(G) = G / (a*G^2+b*G+c)$
- Resulting efficiency dependency at Maximum Power Points
- Values in database defined by manufacturers
- For user defined modules PV*SOL proposes default values depending on cell type.



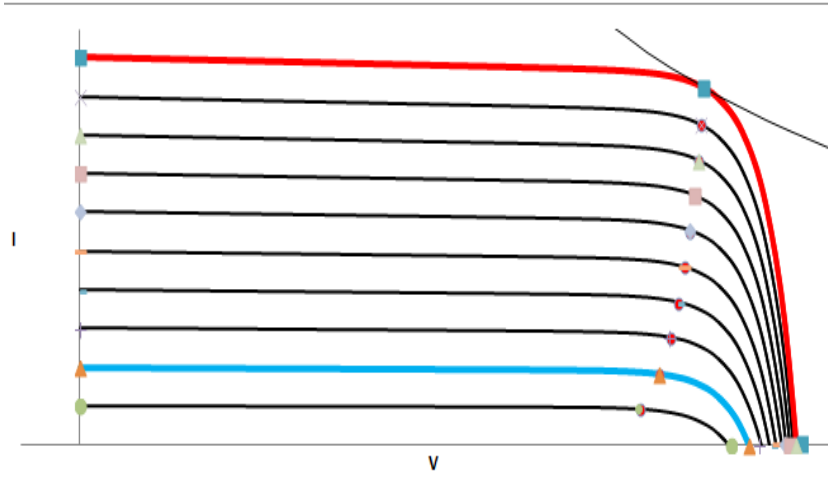
Construction of I-V-Curves

- STC- and $G_{low\ rad}$ – Points
- I_{SC} as linear and U_{OC} as logarithmic function of radiation
- MPPs by fill factor dependency



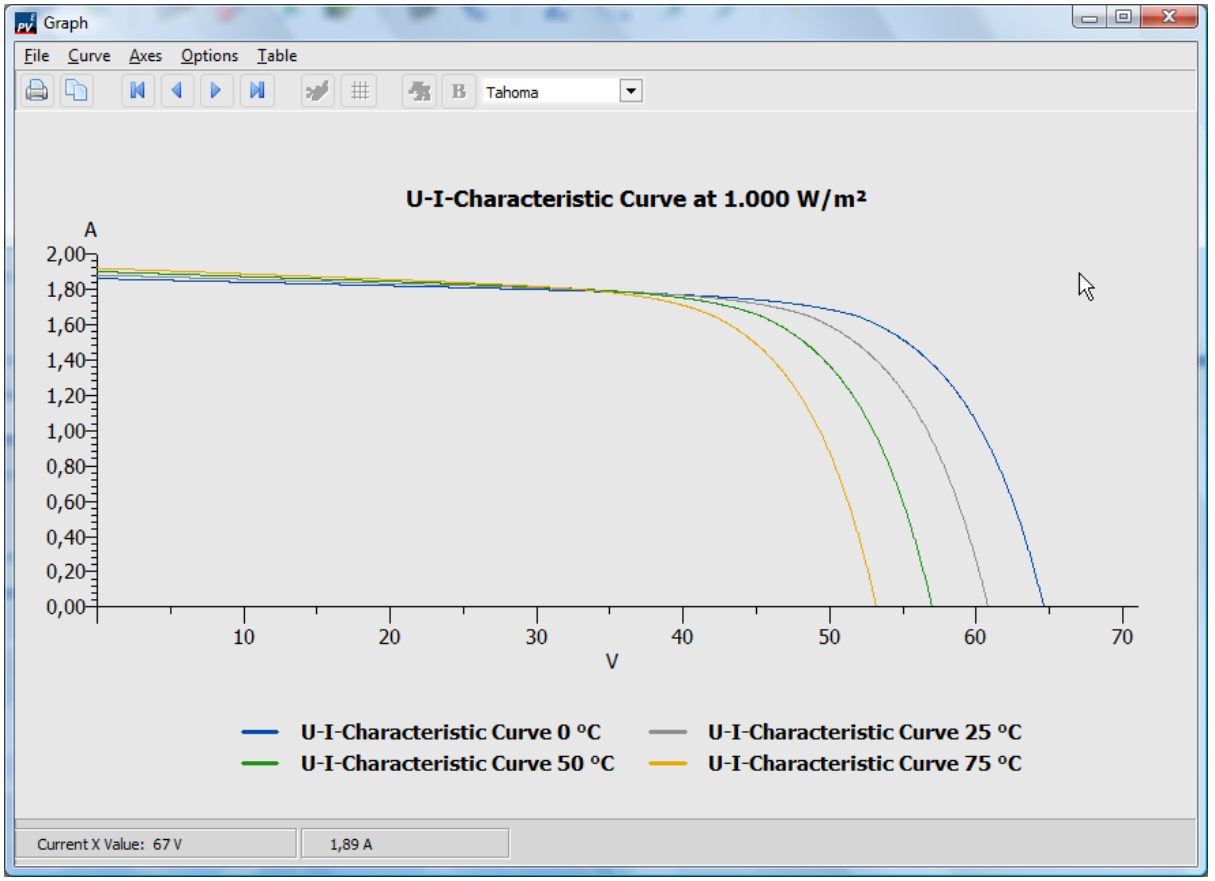
- To the left and right of the MPP the parameters of the 1-diode-model are fitted:

$$I = I_{ph} - I_{sat} * (e^{U/U_T}-1) - U / R_{sh}$$



Dependency on Module Temperature

- Calculated by temperature change coefficients for I_{SC} , U_{OC} and P_{MPP}



Current Work at Module Modelling

- We implemented 1-diode-model and 2-diode-model for those, who know the parameters and prefer these models.
- In general the Valentin model based on STC and **extra low radiation** working points fits better than diode models based on **STC-data only**. This was shown by Martin Hofmann in his master thesis, which is based on indoor and outdoor measurements.
  (see also our presentation on **WREF (ASES)** last year in Denver:
  https://ases.conference-services.net/resources/252/2859/pdf/SOLAR2012_0080_full%20paper.pdf
- We plan to publish the detailed model description at the *PV Performance Modelling Collaborative* (pvpmc.org) .
- Easier parametrizing: Based on STC and efficiency at different radiation, PV*SOL calculates the demanded extra working points.

Summary

Shading calculation with PV*SOL Expert

- Detailled definition of shading objects
- Shading detected on cell level (substrings/stripes)
- Accurate model of PV module
- Explicit connection of modules and strings to construct the MPP (I-V-curves of array)
- Last but not least: The calculation is fast.

Thank you

for your attention!