
FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

SmartCalc.CTM – cell to module analysis by Fraunhofer ISE



SmartCalc.CTM development team
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Systems ISE

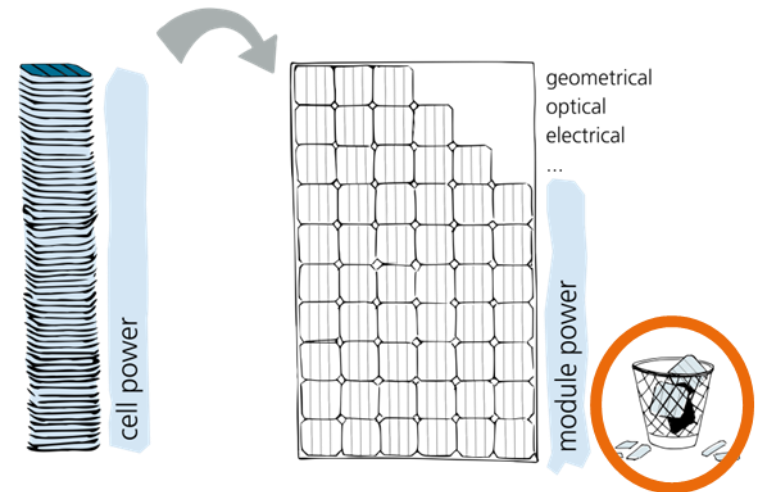
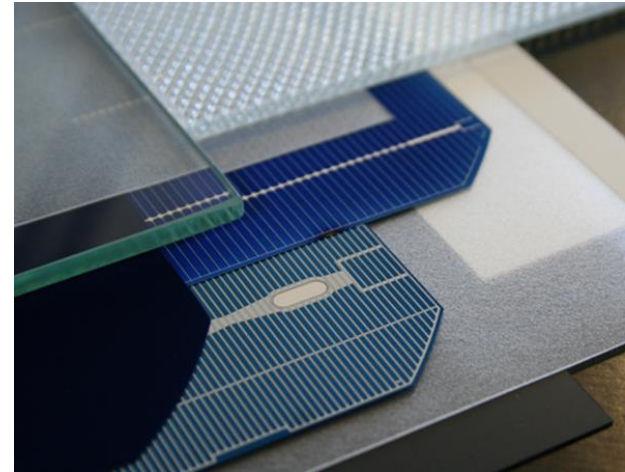
Weihai (China), 05.12.2017

www.ise.fraunhofer.de

Cell to Module Analysis

Motivation

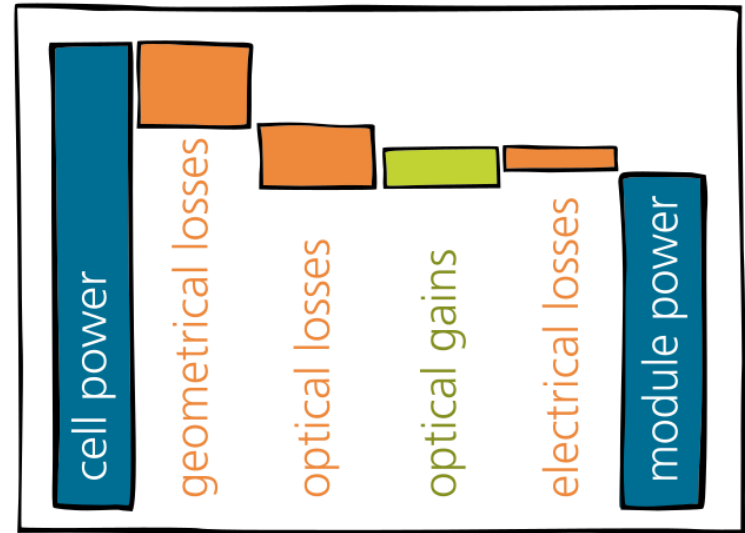
- Module materials (BoM) and module setup/concept influence power output
- Cell power > module power
- Power losses = financial loss (\$/Wp)
- CTM-ratio currently at ~98.5% (1)
- **1.13 \$ per module** CTM-loss (300 Wp, 0.25 \$/Wp)



Cell to Module Analysis

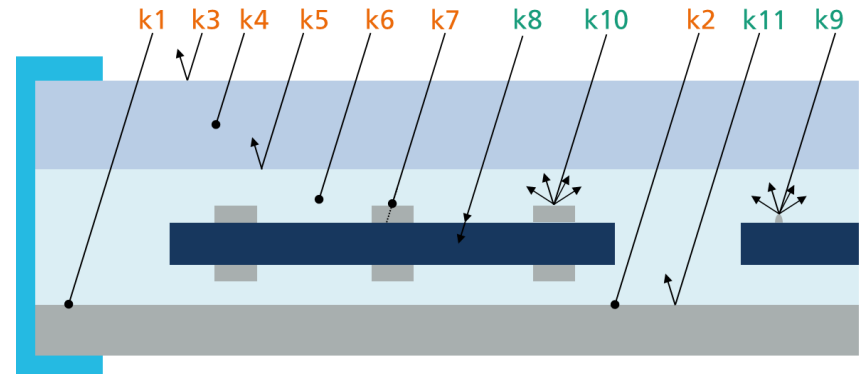
Motivation

- Identification of hidden power potentials
 - Cost effective performance improvement
 - Evaluation of new technologies
 - **Precise CTM-analysis required**
-
- CTM-factors influence each other
 - **Non-trivial optimization of a complex system**

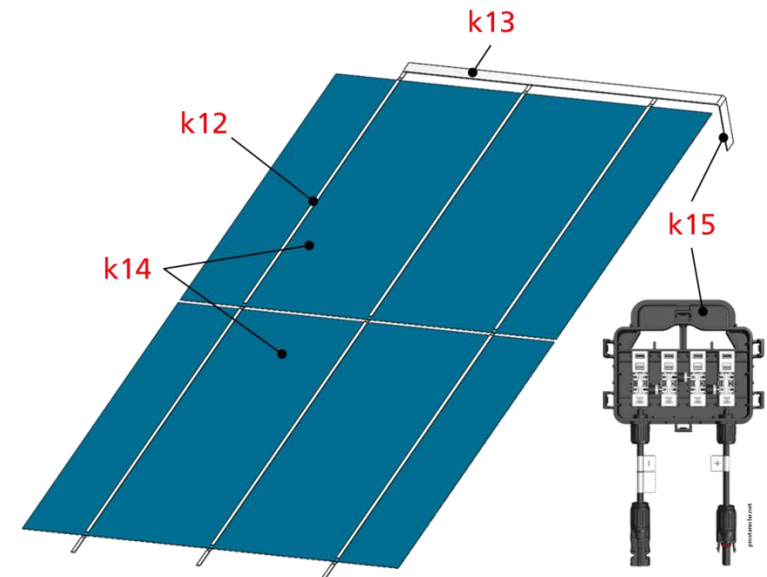


Cell to Module Analysis by Fraunhofer ISE

- Detailed analysis of gain and loss mechanisms
 - Characterization procedure
 - Calculation of 15 gain & loss factors
 - Bottom up: based on material properties and module setup
- Analysis of existing concepts and modules
- Advanced models allow calculation of new concepts



Geometrical and optical gain & loss mechanisms

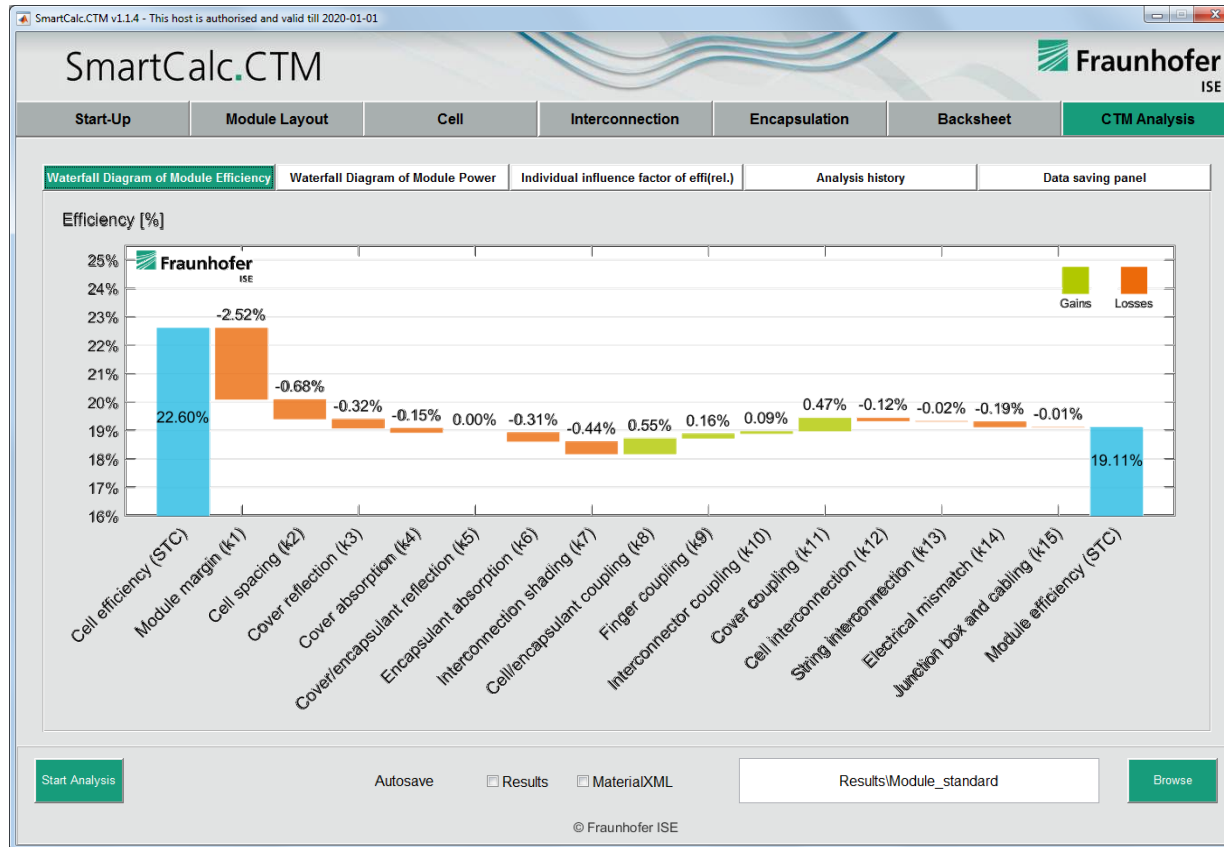


Electrical loss mechanisms

Cell to Module Analysis by Fraunhofer ISE

www.cell-to-module.com

Free demo version available

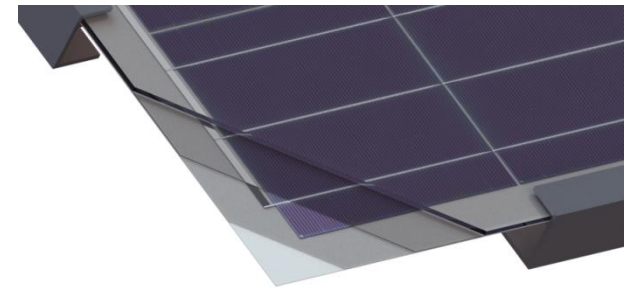


- Accuracy and scientific quality are important to improve PV modules
- Flexibility, usability and accessibility required by industry and other users

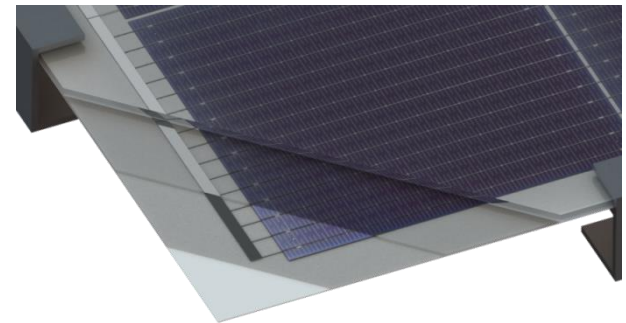
Flexibility in CTM-analysis

Diversity of PV Modules

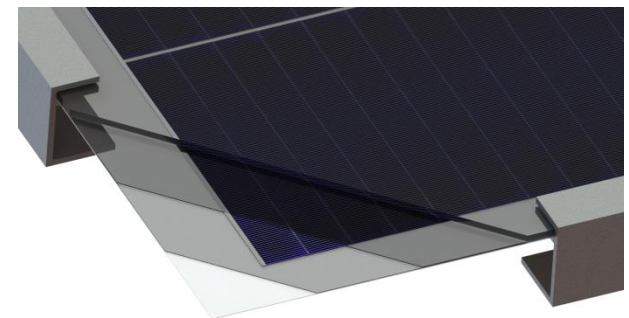
- Module concept
 - Glass-glass, bifacial modules,...
- Module layout
 - Numbers of cells & strings, Serial & parallel string interconnection,...
- Interconnection technology
 - Shingled cells
 - Round wire ribbons
 - Electrical Conductive Adhesives
 - ...
- Module materials & properties of components



H-pattern cells and ribbons



Round wire interconnection

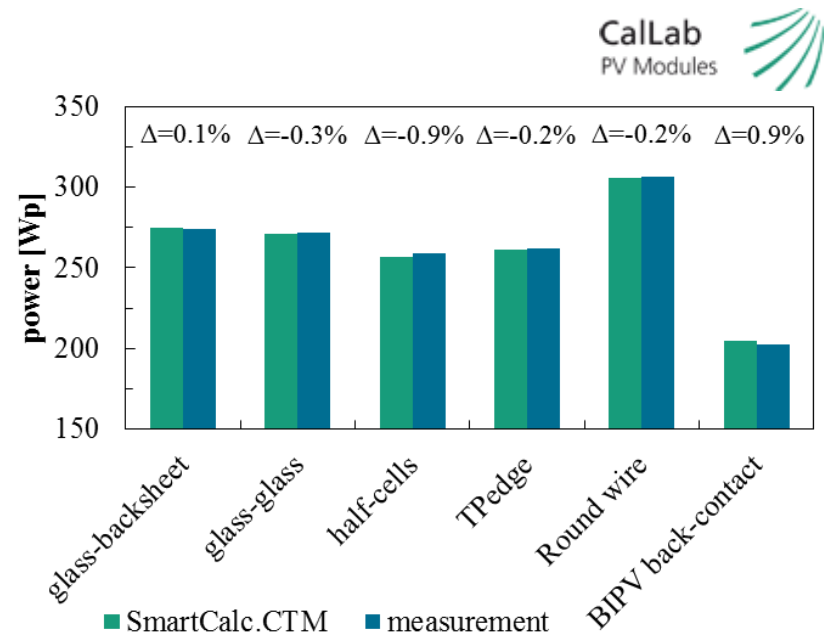


Shingled solar cells

SmartCalc.CTM

Precision & Validation

- Modules of different setup build & simulated
 - Glass-backsheet / glass-glass
 - Full cells / half cells
 - Round wire cell interconnection
 - BiPV back-contact module
 - TPedge
- Measurements for Validation at Fraunhofer ISE Callab PV Modules



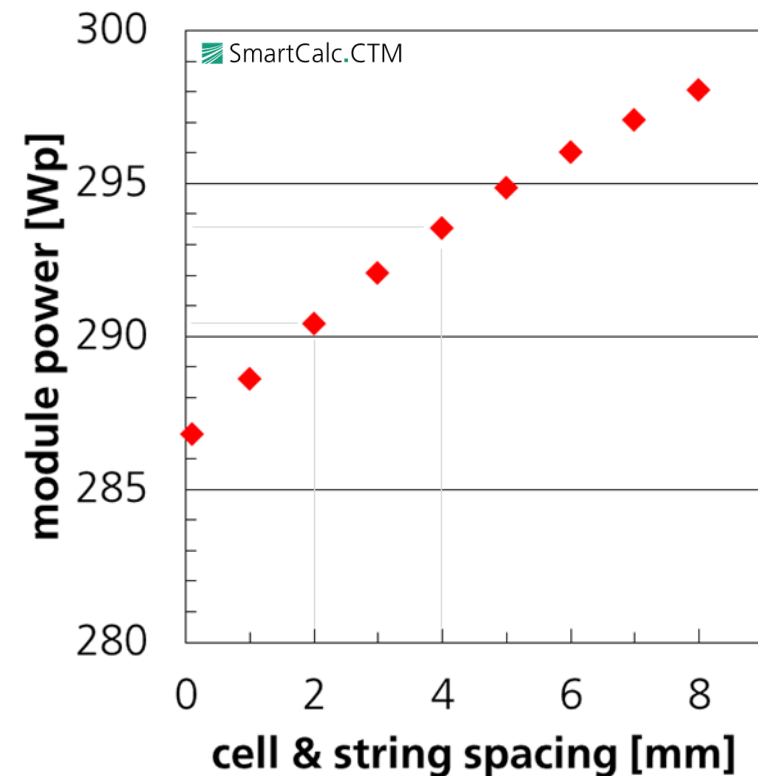
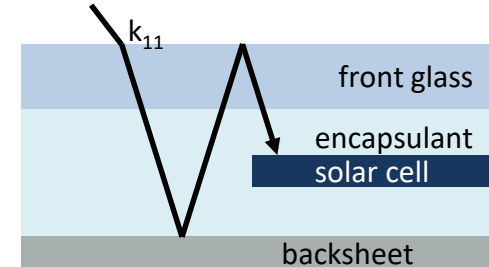
→ SmartCalc.CTM is a precise tool

How is a CTM-analysis improving module power?

Module Optimization

Cell & String Spacing

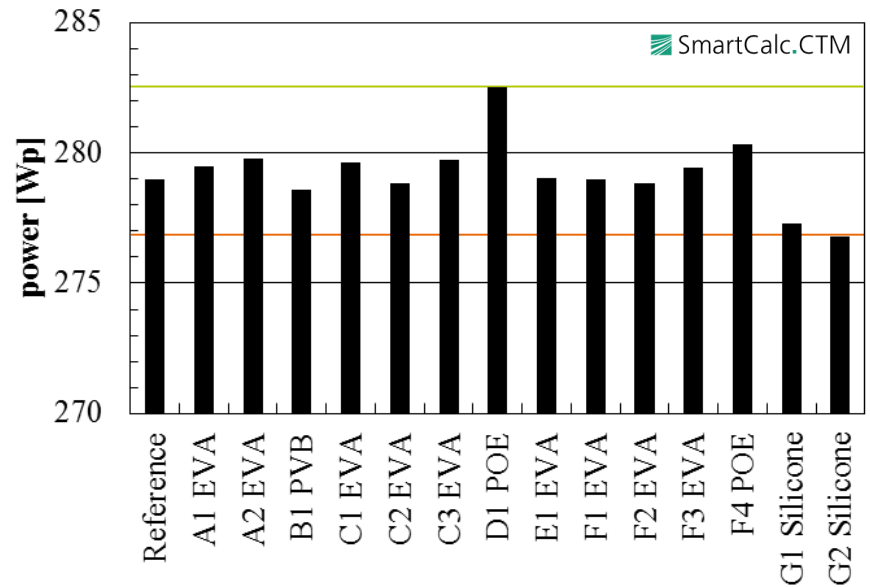
- Cell and string spacing influences
 - Backsheet reflection gains
 - Electrical losses
- Increase of spacing leads to higher module power
 - +1.1% (2 mm → 4 mm)
- Evaluation of gains possible
 - Material costs vs. power gain



Module Optimization

Encapsulants

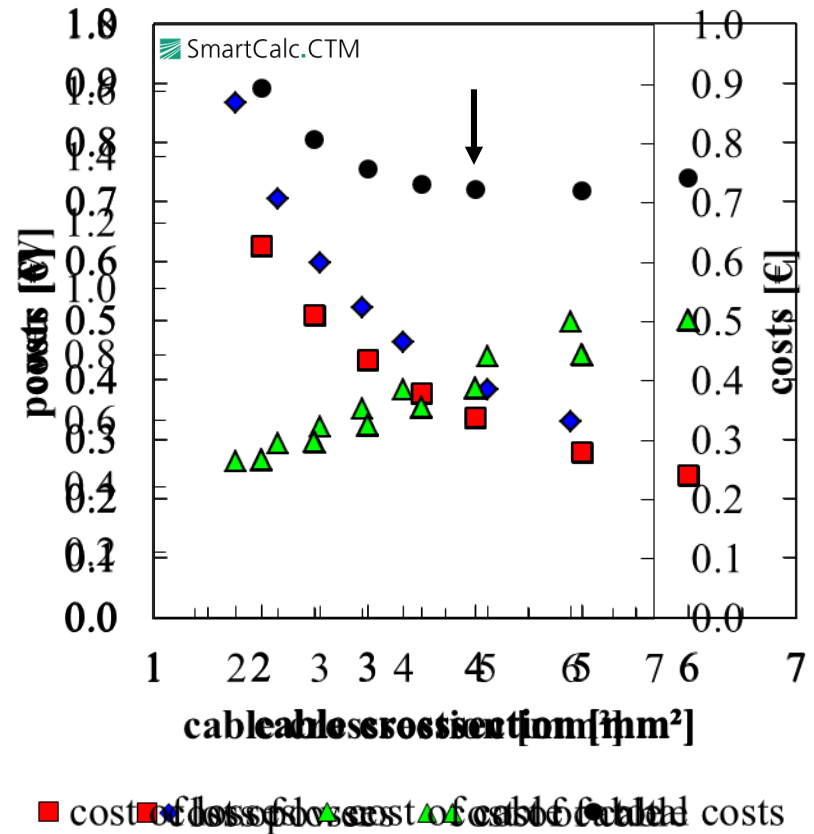
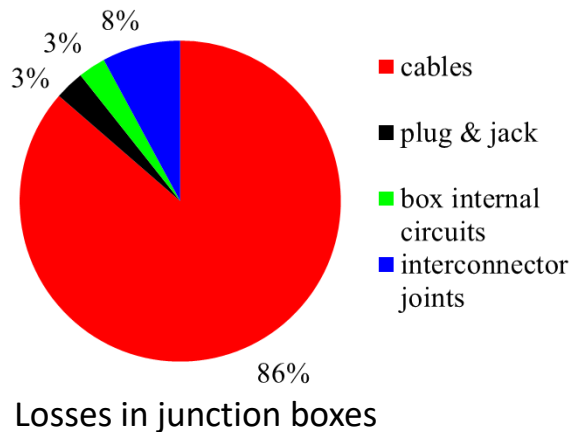
- Change of encapsulant
 - 14 materials
 - 6 manufacturers
- Calculation of effect on module power
 - Max – Min = 2.1% (5.8 Wp)
 - Max – Min = 1.3% (3.7 Wp) for EVAs
 - Choice of encapsulant essential for high module power



Module Optimization

Junction Box

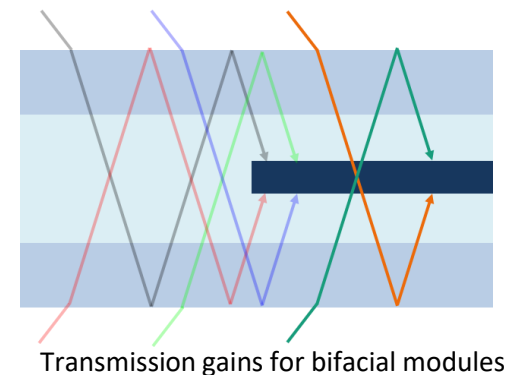
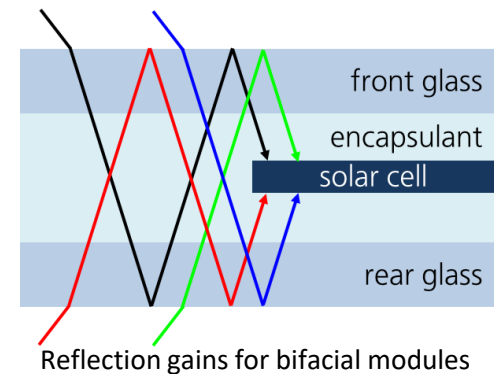
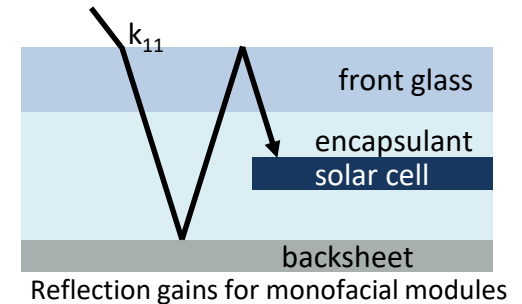
- Cable cross section influences
 - Price of cable
 - Junction Box Losses
- Power losses can be translated into financial loss (€/Wp)
- Optimal cross section



Module Optimization

New Concepts: Bifacial Cells

- CTM-analysis of common module & cell concepts possible
- Novel concepts require new CTM-models
- Bifacial cells
 - Additional gains from internal reflection
 - Gains from partial transmission of bifacial solar cells



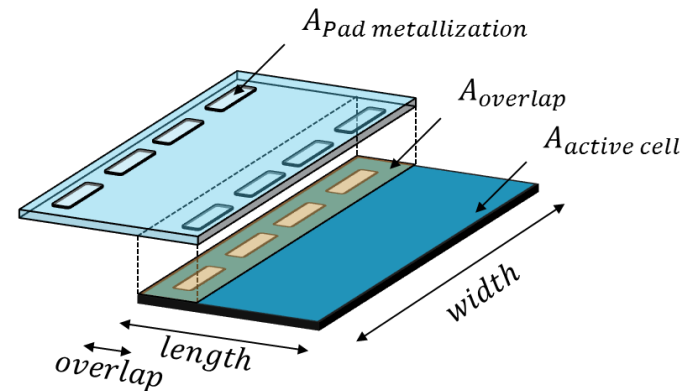
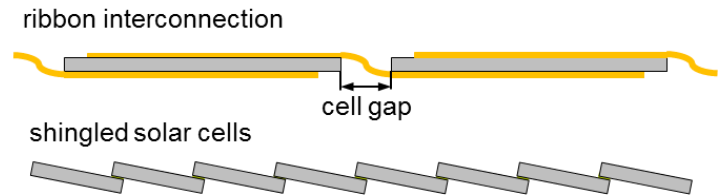
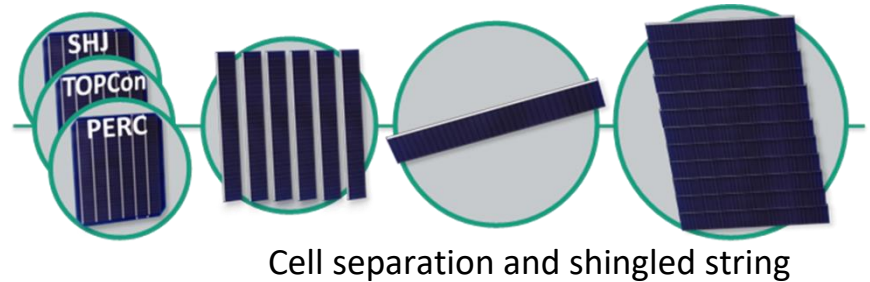
Module Optimization

New Concepts: Shingled Solar Cells

- Overlapping solar cells
- Optical CTM-factors affected

- Active cell area shaded by active cell area
- No cell gap

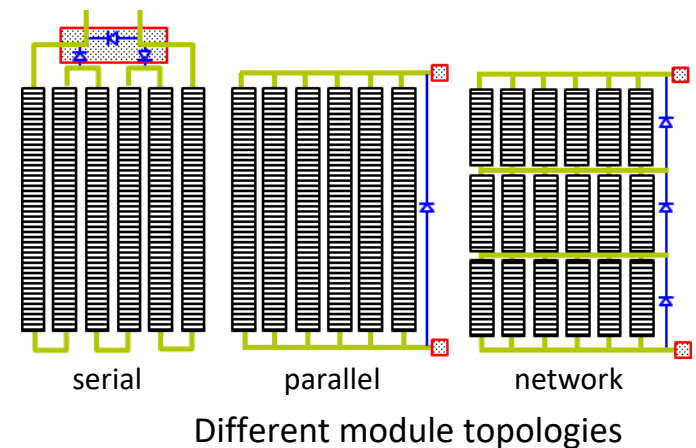
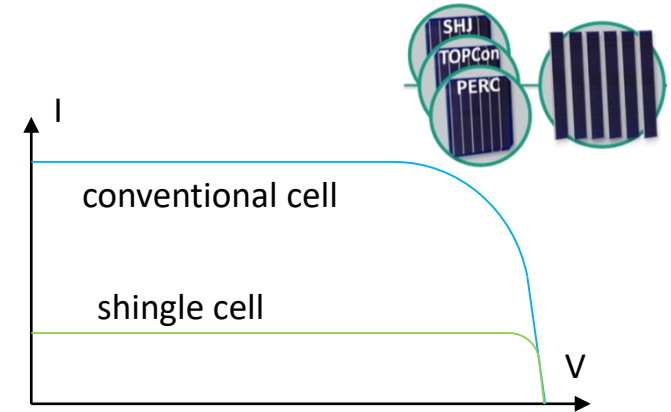
- Increased active area in modules
- High module efficiency



Module Optimization

New Concepts: Shingled Solar Cells

- Smaller solar cells
- Changes in cell IV-curve
- Change of
 - module IV-curve OR
 - module topology
- Shingled modules do not require cell interconnection ribbons
- Flexible models for analysis of shingled modules necessary



Module Optimization

2.4%_{power} gained
without building a single prototype

Common module

CTM-losses: 7.8 W
= 1.95 \$ (@ 0.25 \$/Wp)

Change of

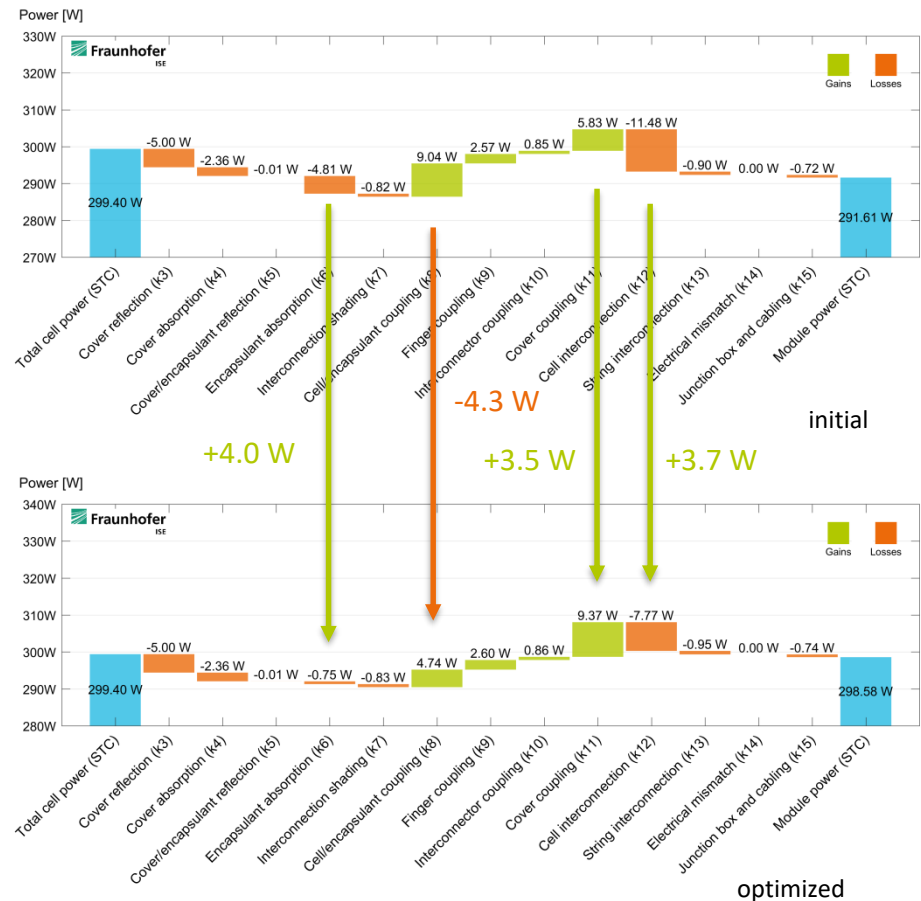
Interconnector thickness from 0.15 mm to 0.25 mm

Change of EVA

Change of cell and string spacing from 2 mm to 4 mm

→ + 7.0 Wp (= 1.74 \$)

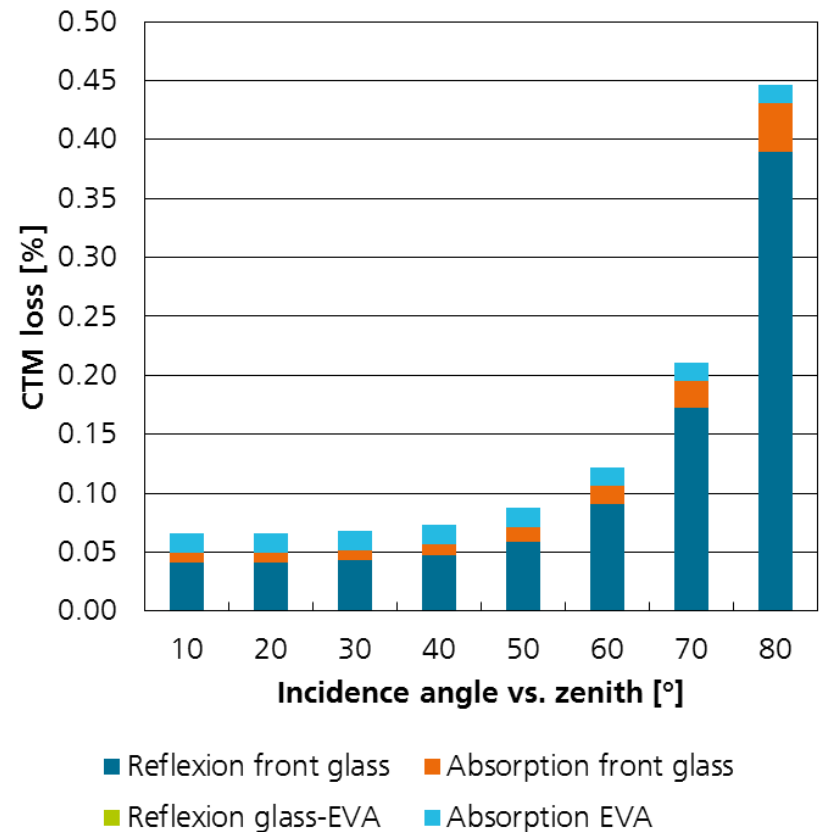
→ Economic analysis possible



Module Optimization

Preview: Non-STC

- Module optimization for Standard Testing Conditions (STC) with limited
- Flexible models allow calculation of CTM-factors for non-STC conditions
- Module Optimization for selected environments & locations
- Analysis of single contributing factors possible



Why simulate modules
when you can simply build them?

SmartCalc.CTM

Computer Aided Development

- Prototyping is expensive and difficult for new technologies
 - Manufacturing equipment is usually not available
 - Processes are not optimized for single prototypes
 - Prototypes only allow assessment of the complete module
 - Identification of promising development routes possible with software
 - What-If-Analysis
 - Parameter Sweeps & Sensitivity Analysis
 - Virtual Prototyping
- Computer Aided Development saves costs in an iterative PV module development

Thank you for your attention!



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