Ray tracing methodology for Bifacial System modeling: Exemplar and Validation

应用光线追踪方法建模双面电站系统: 范例与验证

photo provided by NEOEN

薄中南 Jefferson Bor

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Special thanks to

Dr. C. Reise, J. Kang, Fraunhofer ISE

M.Chiodetti, EDF

Fraunhofer Institute for Solar Energy Systems ISE

PVPMC, Weihai, 05.12.2018

Fraunhofer ISE

议程
AGENDA

1. 双面建模的挑战
2. 光线跟踪法如何运作?
3. 实际应用范例
4. 模型验证
5. 结论与展望

1. Main Challenges for Bifacial Simulation
2. How does Ray Tracing Method Works?
3. Project and Test Exemplars
4. Validation of the Model Performance
5. Conclusion and Perspectives

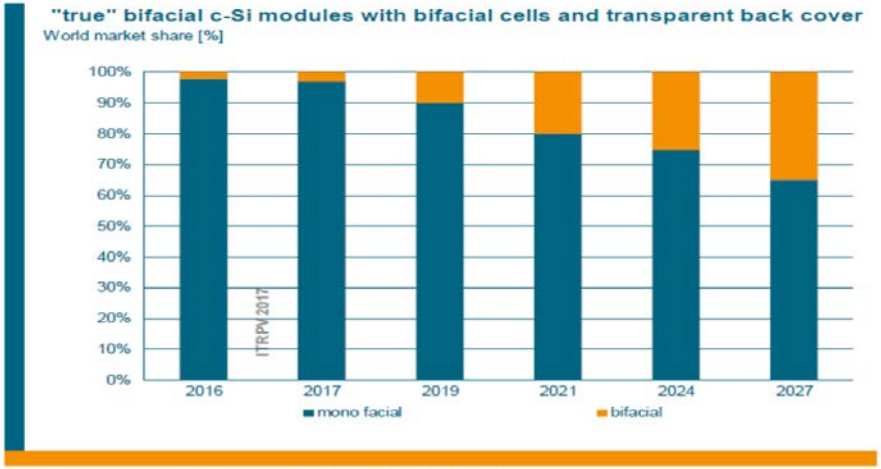


Fig. 43: Worldwide market shares for monofacial and "true" bifacial modules.

Expected development of monofacial and bifacial modules share of the world market

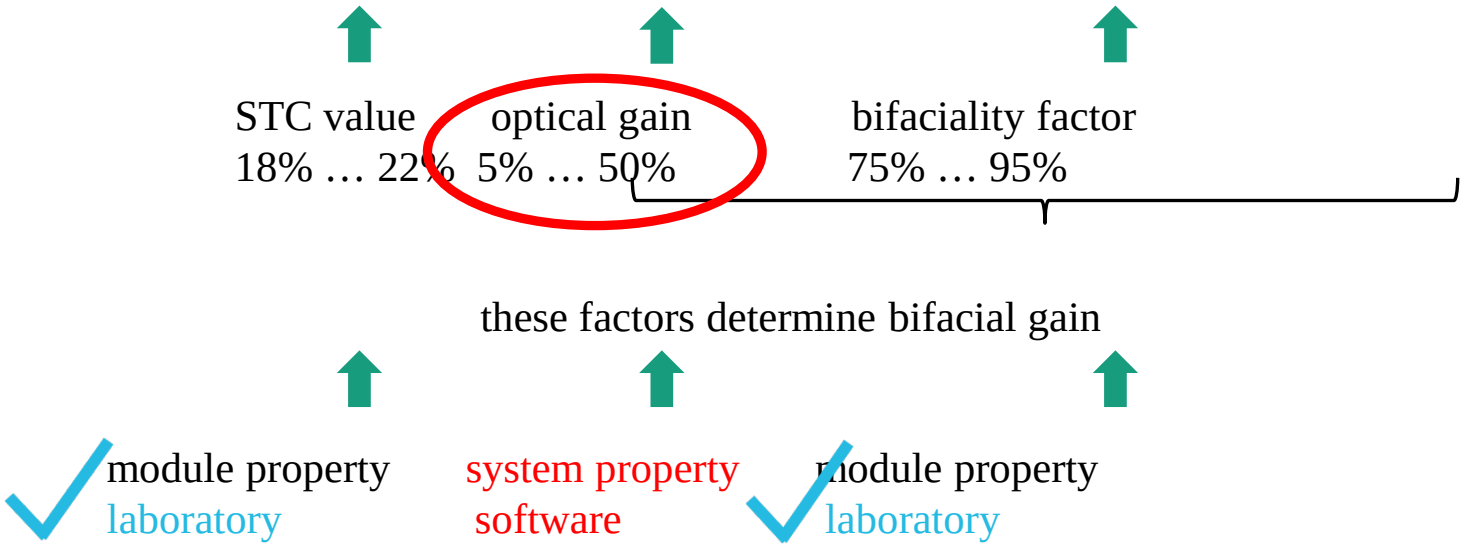
Source: ITRPV report 20171

双面的效率与发电 Bifacial Efficiency and Power

一个直观的想法 A Straight Forward Thinking

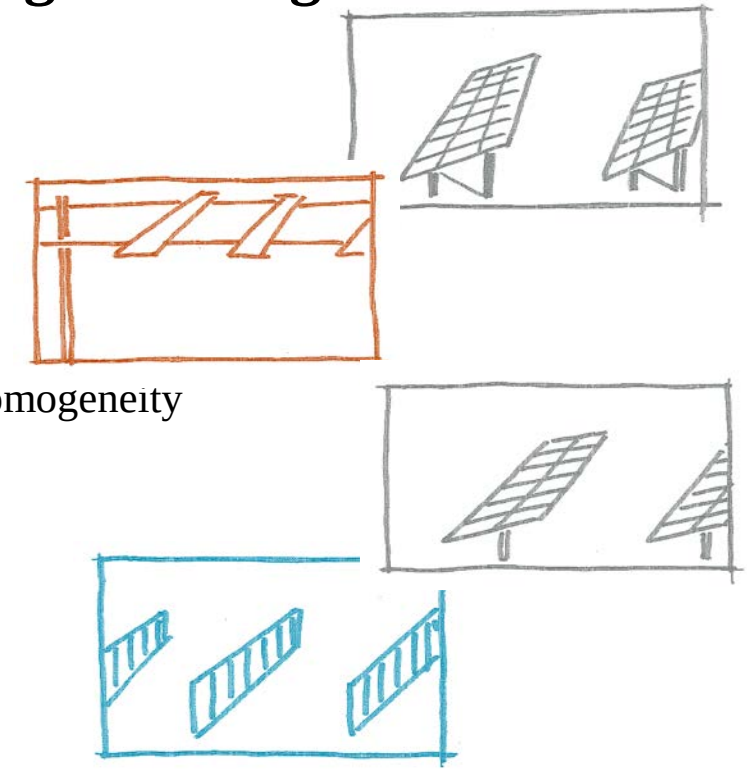
Yield ~ G(front) * eff(front) + G(rear) * eff(rear)

= G(front) * eff(front) + G(rear) * eff(front) * BF



影响双面增益的因子 Factors affecting bifacial gain

- 支架几何 the mounting geometry
  - 高度 height
  - 倾角 module tilt
  - 间距 row-to-row distances (GCR)
- 地面反射率与不均匀度the ground albedo and its homogeneity
- 支架结构 the mounting structure
- 组件双面特性 Bifacial characteristics of module



→许多因素并不影响单面系统的模拟

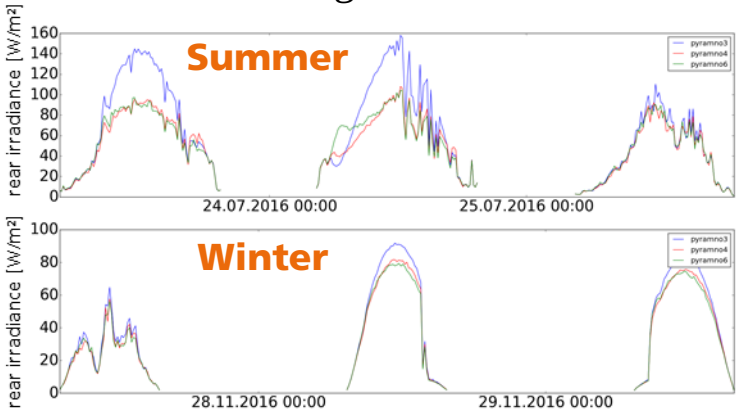
Mono-facial system simulation is not affected by most of these factors!!

双面模拟的挑战 Main challenges for bifacial simulation

- 背面辐照不均匀 Non-uniformly distributed radiation on the rear side
- 周遭物体都有不同的反射或散射特性

  All surrounding objects have different patterns of reflection and scattering

- Other adaptation compared to mono-facial model
  - Electrical modelling for the two-side irradiance
  - Modified thermal behaviour



Measured irradiance from 3 pyranometers mounted on the rear side of a bifacial system

双面系统的建模 Modeling of bifacial system

- 主要的两种模型 Two dominating method for modeling:
  - View factor method

    JCT, ECN, CEA INES, ISC KONSTANZ, REC, SERIS, Sandia, NREL, University of Iowa, RTWH,, Enel, Pvsyst, Polysun, University of Nevada, Fraunhofer CSP, ZHAW, Univertsity of Stuttgart, KAUST…[1]

  - **光线跟踪法 Ray tracing method**

    Fraunhofer ISE, EDF[1] , SERIES Singapore

[1] Source: J. Libal et al., bifi PV workshop October 26, 2017

The View Factors Method

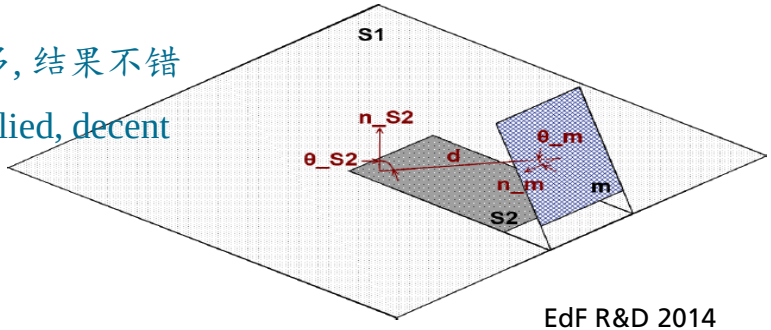
- View Factor : fraction of radiation from s1, s2 (or more) that hits the m surface

优点 Pros

- 较容易应用 Can be easily implemented
- 运算快速 Low computing time

→使用者多, 结果不错

Mainly applied, decent result



EdF R&D 2014

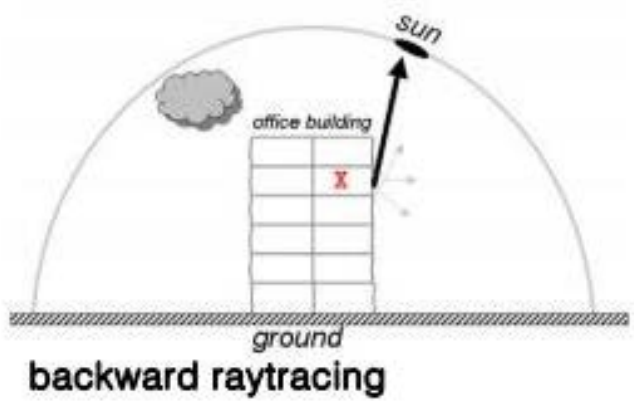
缺点 Cons

- 复杂的形状较难考虑 Complex geometries are difficult to be considered
- 支架结构与外物遮蔽等细节较难整合

  Mounting structure and shading objects are hard to be integrated

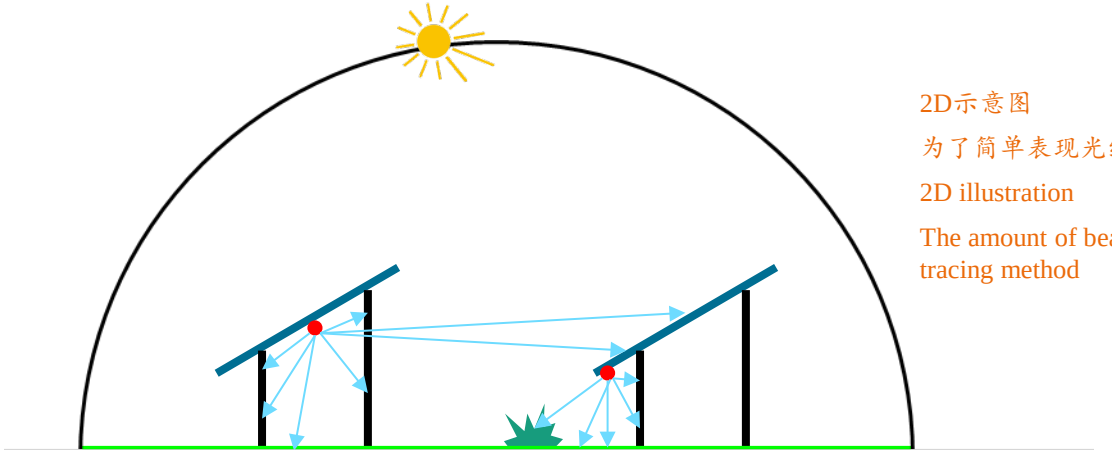
光线跟踪法 The Ray Tracing Method

- 反向光线跟踪计算 Backward ray tracing calculation



光线跟踪法 The Ray Tracing Method

- 光线发射后-每束光开始经历: Light begins to travel back – each beam will:
  1. 碰到障碍物 Hit obstacles …根据周遭环境 depending on surrounding
  2. 镜面反射或散射 Specular reflect or scatter …根据材料表面 depending on material surface
  3. 最终到达天空 (半球顶) Hit the sky (hemisphere)



2D示意图

为了简单表现光线跟踪法概念图中简化光束数量

2D illustration

The amount of beams is reduced to better conceptualized the ray tracing method

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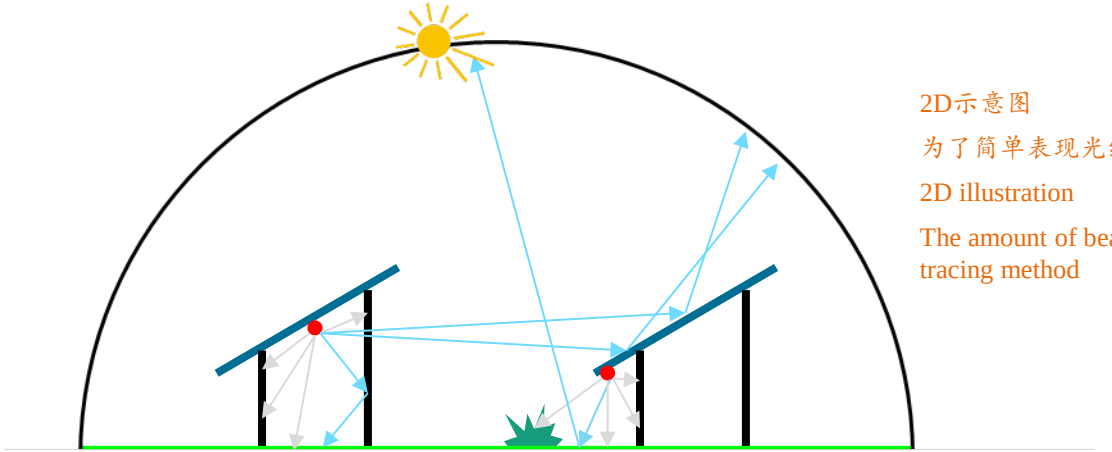

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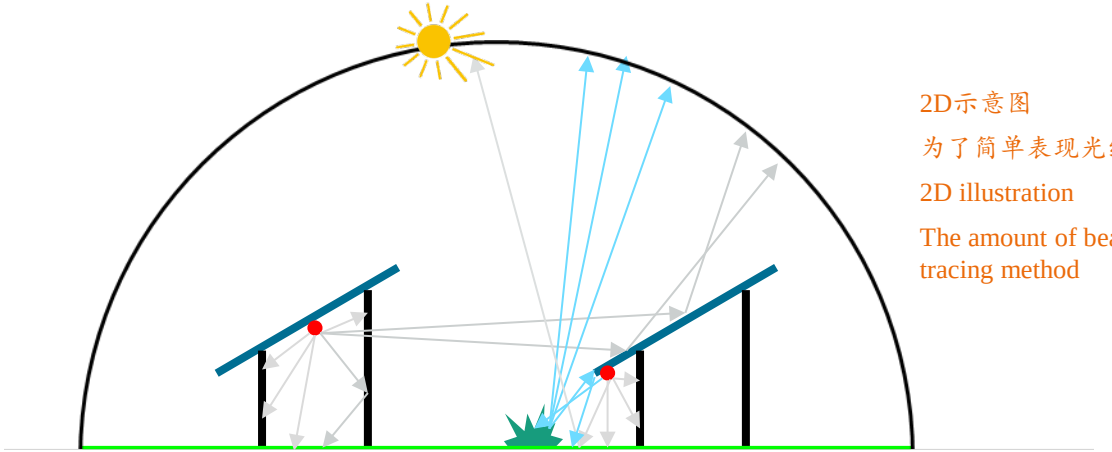

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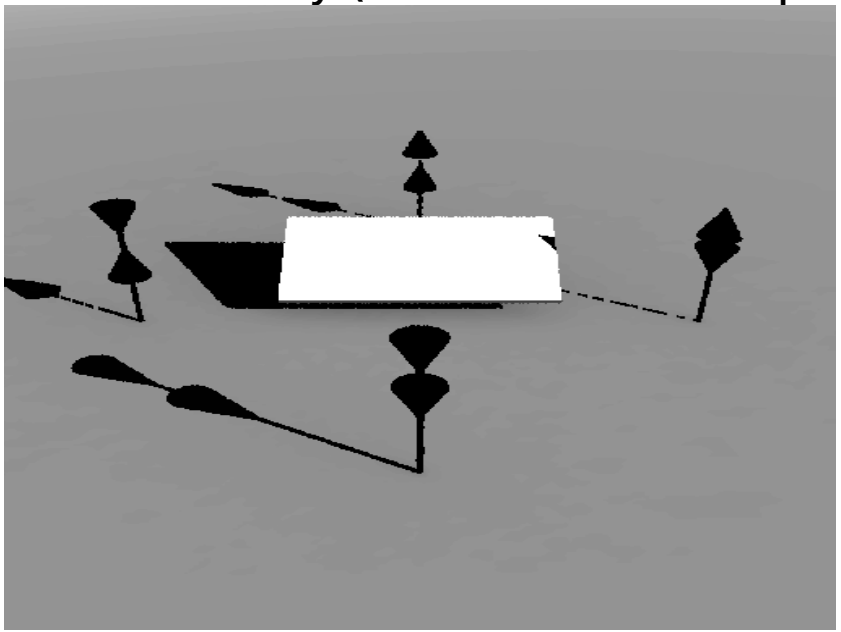
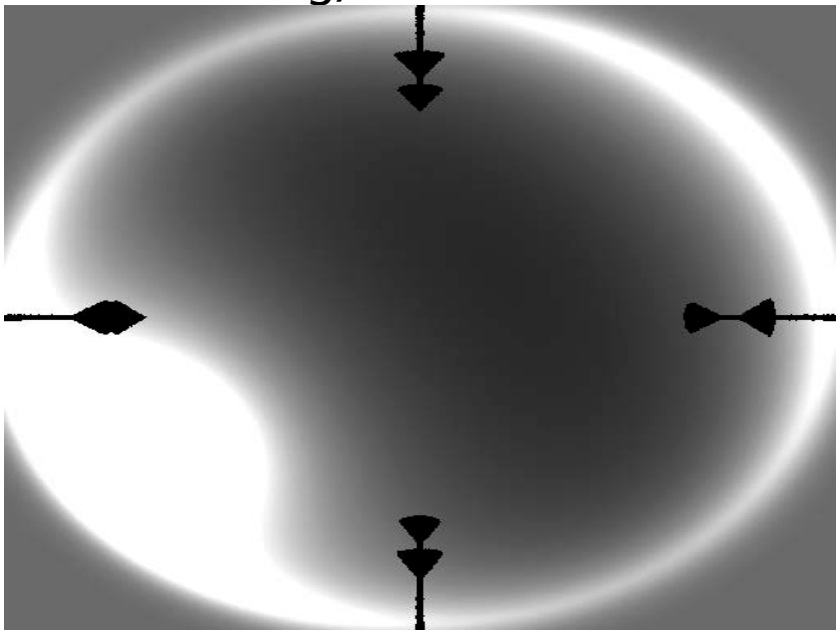
按角度解析的辐照值 Angle-resolved Irradiance Value

辐照密度场 Radiation Density Fields

Model and Sky (9 O'Clock at 21. September in Freiburg)

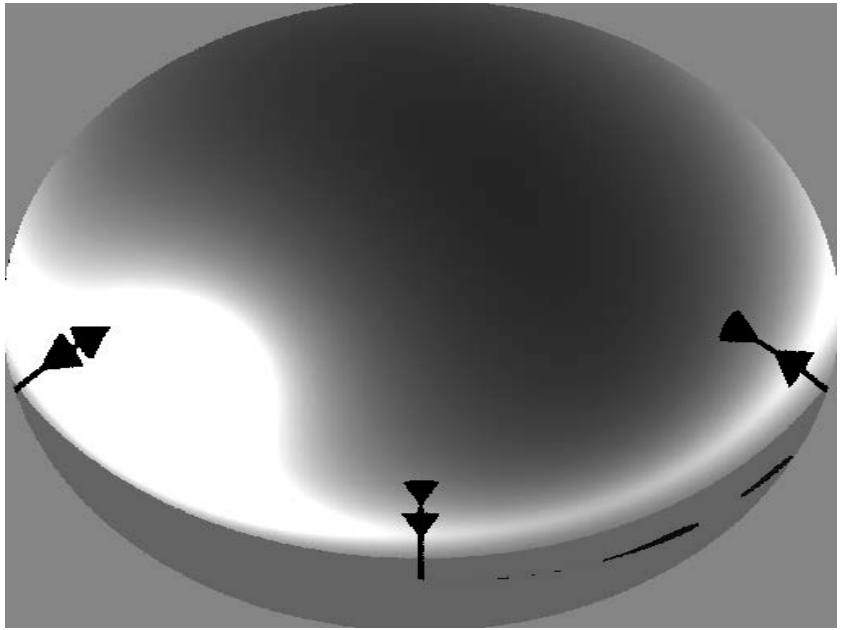


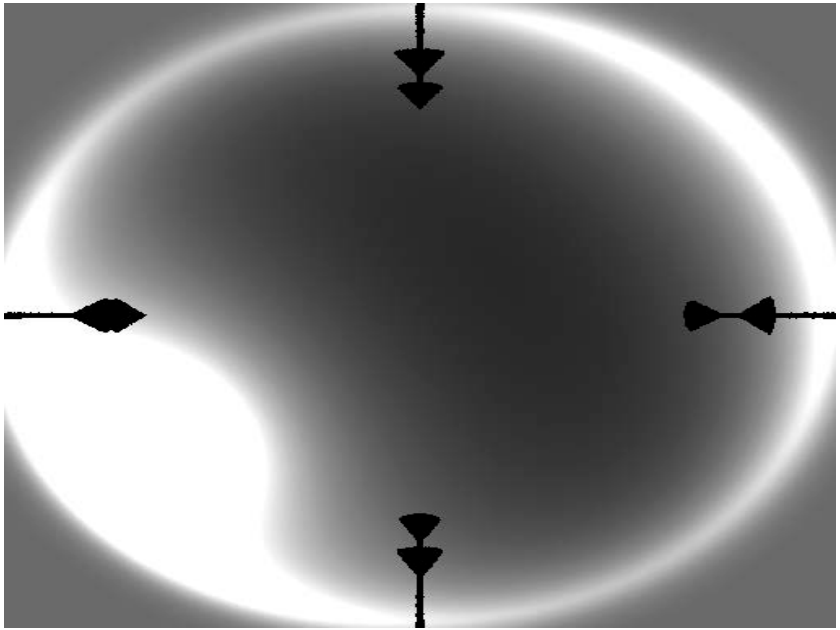


按角度解析的辐照值 Angle-resolved Irradiance Value

辐照密度场 Radiation Density Fields

正面 Field of view, front side





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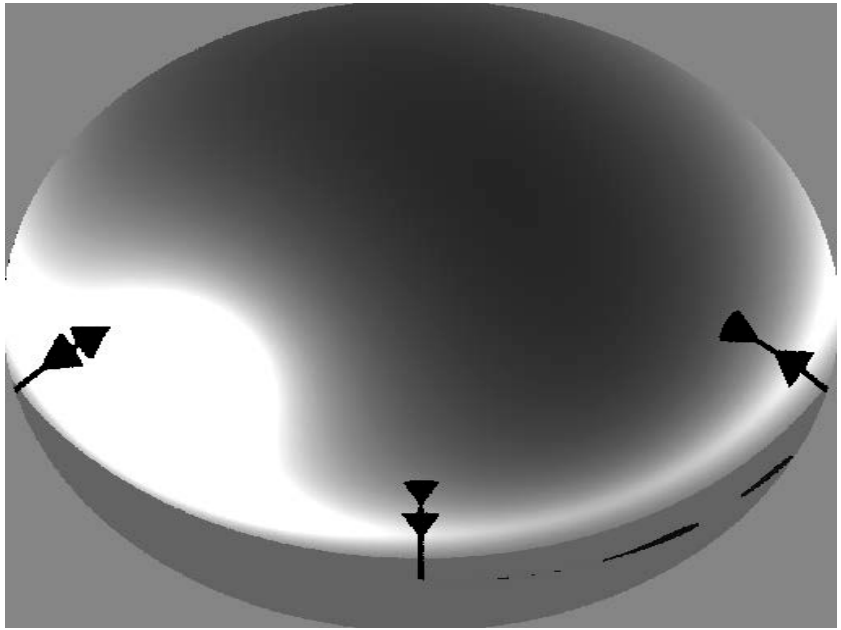
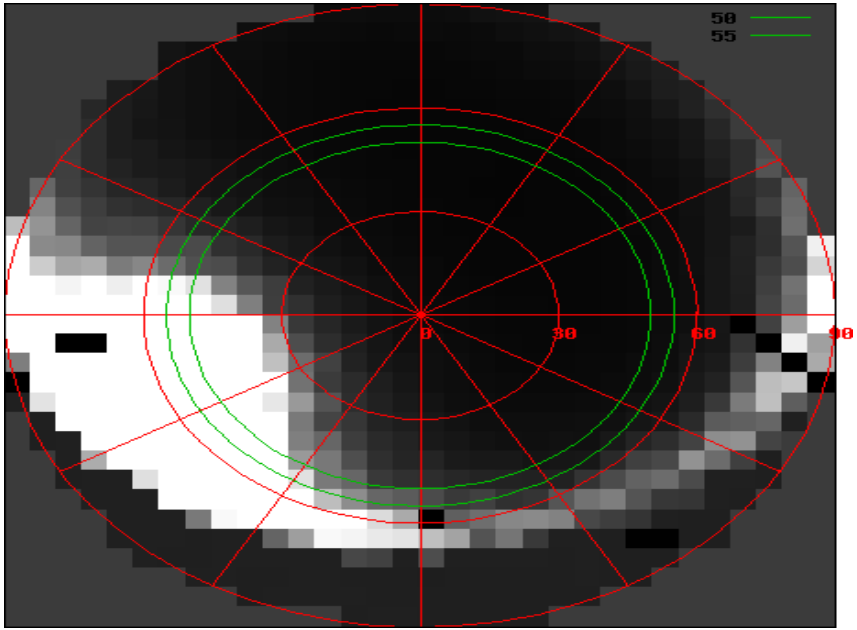
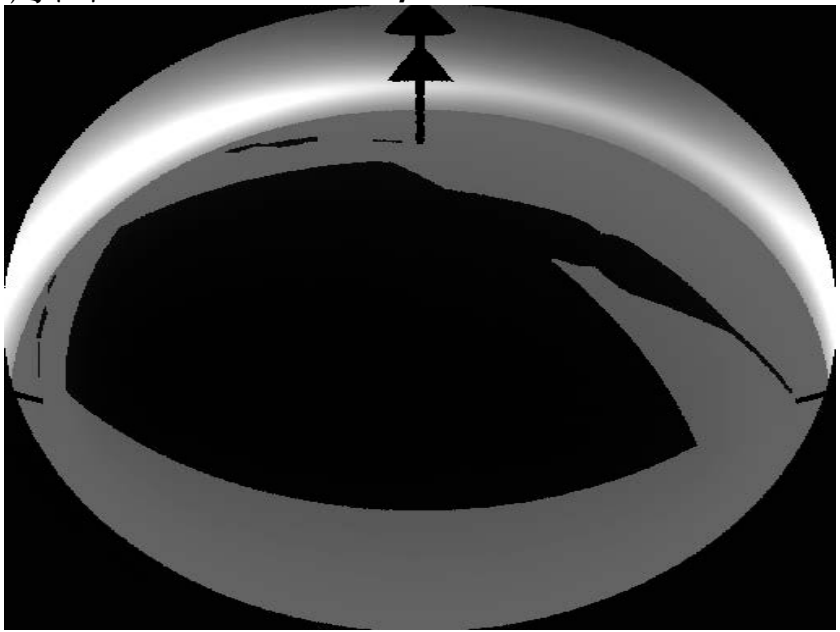


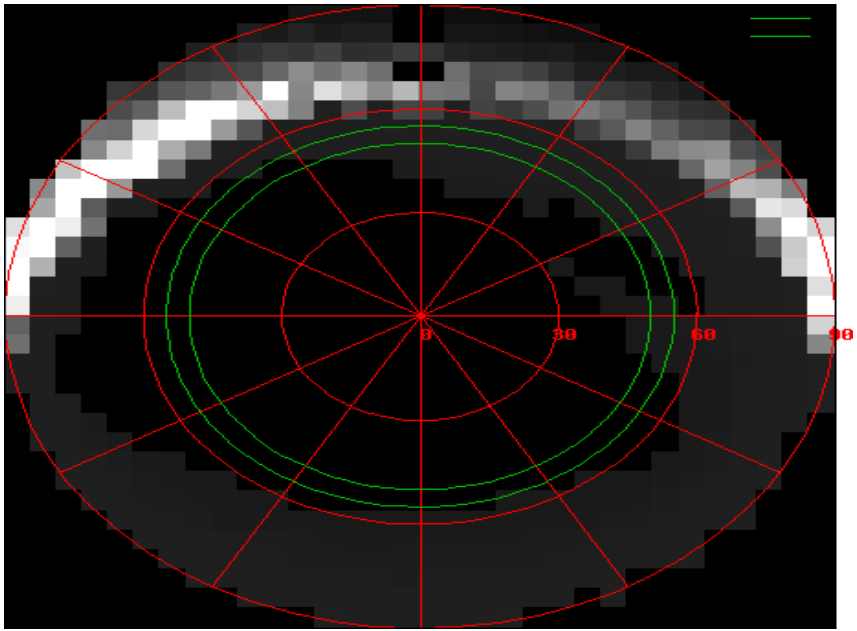


按角度解析的辐照值 Angle-resolved Irradiance Value

辐照密度场 Radiation Density Fields

背面 Field of view, rear side





光线跟踪法 The Ray Tracing Method

- → 想象成: 背面每一观察点有一个假想的传感器

  Just image: Virtual Sensor on each defined point

- → 求全部点平均

  Average of all points

每个点会射出1024条光线

每一次的反射后，每一条会再变成至多1024条…

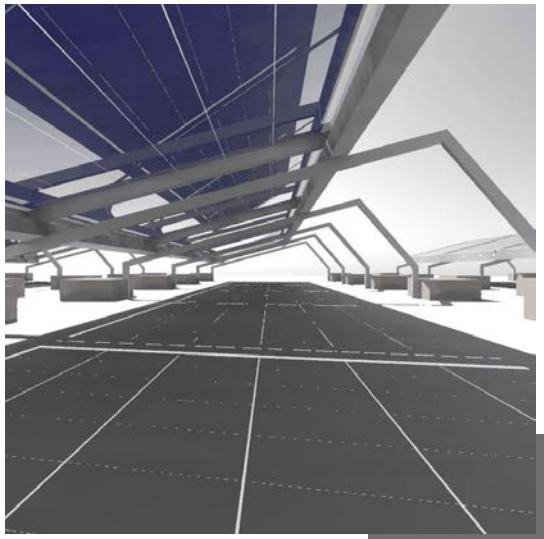
举例: 3次反射后我们总共会有10^{12} 条光束…

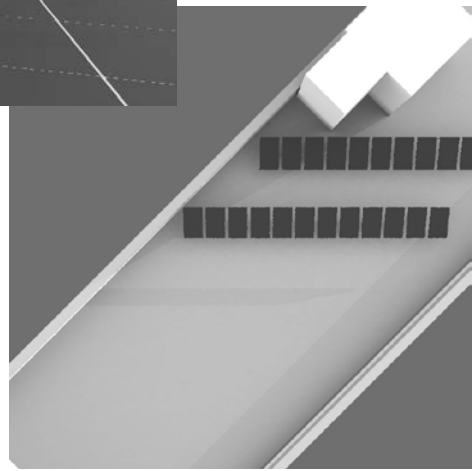
1024 Beams sent out from each point

After each reflection, one beam will become 1024 beams…

Ex: after 3 reflections, we will get max. 10^{12} beams…

光线跟踪法
The Ray Tracing Method





优点 Pros

- 贴近真实的背面辐射 Realistic rear side irradiance
- 3D的不均匀分布 Considering inhomogeneity in 3D
- 可以重建细节(结构,空间分布, 物体)
  Possible to build up all configurations (structure, spacing, objects)
- 可以整合CAD软件 Possible to feed-in with CAD software

缺点 Cons

- 较不易整合进现有模型 Less easy to implement
- 计算较为耗时 Computing time consuming

光线跟踪法应用实例 Appliance Exemplar with ISE Ray Tracing Model

85MW 约旦 85MW, Jordan

- 85MW, Jordan
- 2302 kWh/m² (avg. 2008-2017)
  - DNI: 1738 kWh/m²
  - DHI: 564 kWh/m²
- Bright sand – Abeldo: ~30%
- Bifacial module, 76% bifaciality factor
- Horizontal single axis tracker
- Row distance: 13m (GCR 31%)
- Height: 2.8 meter

Dark rocks and soil will be removed to expose the white sand

Source: : Soltec, https://soltec.com/soltec-unveils-the-sf7-tracker-that-achieves-higher-yield-and-lower-cost/

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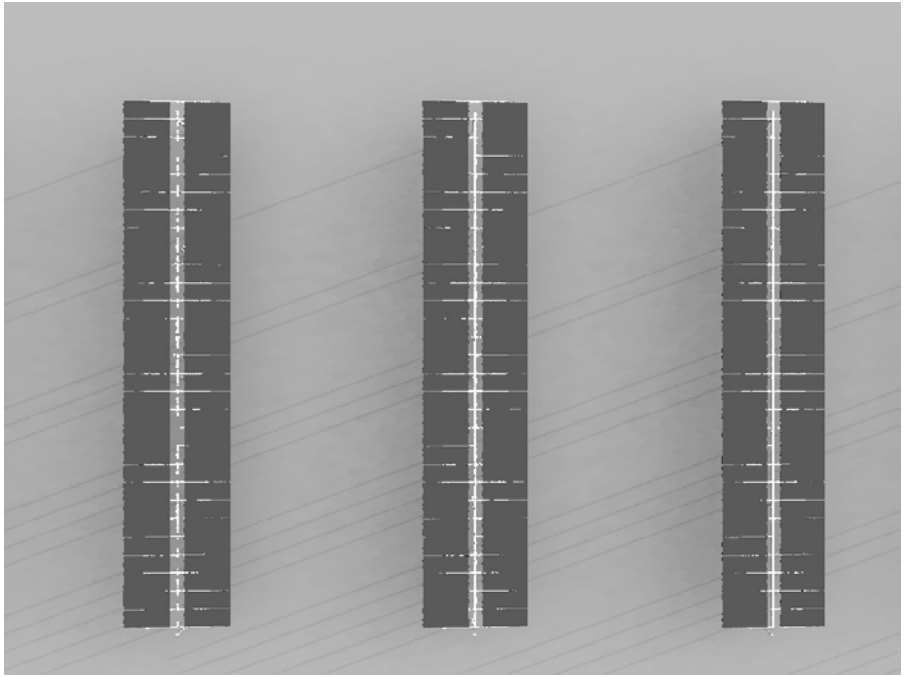
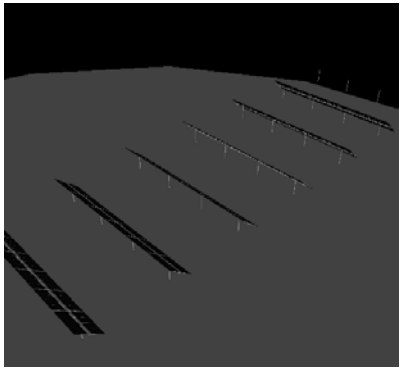
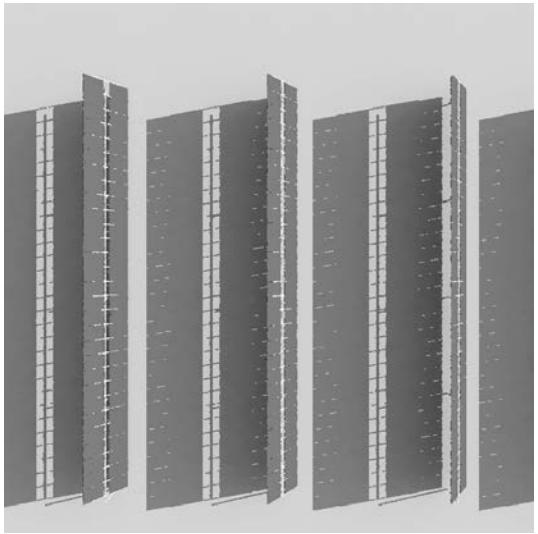




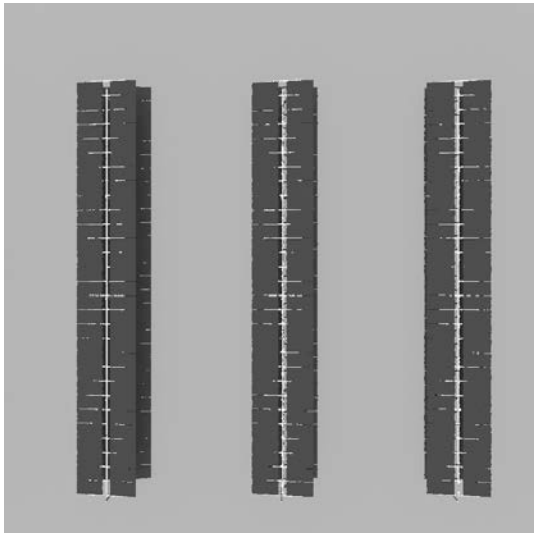
光线跟踪法应用实例 Appliance Exemplar with ISE Ray Tracing Model

日变化, 85MW 约旦 Daily Change 85MW, Jordan

6 am



12 pm



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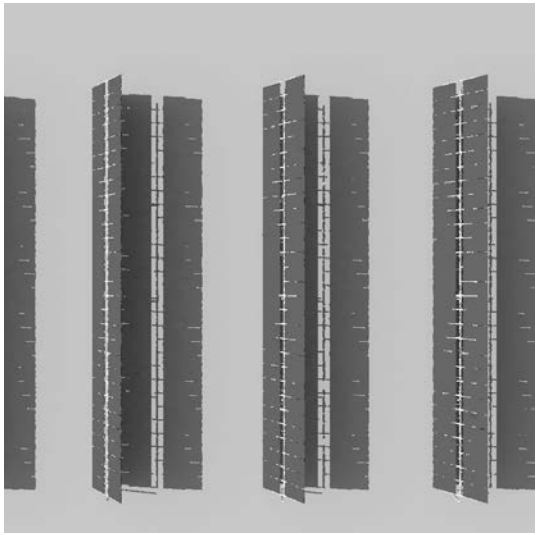
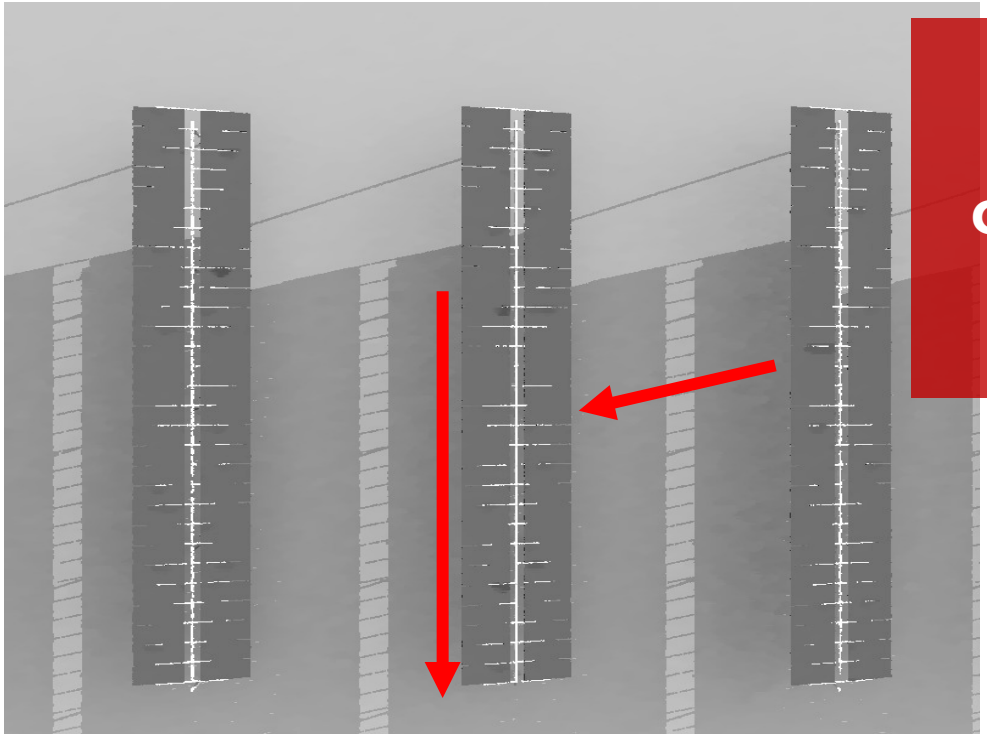


光线跟踪法应用实例 Appliance Exemplar with ISE Ray Tracing Model

日变化, 85MW 约旦 Daily Change 85MW, Jordan

光线跟踪法应用实例 Appliance Exemplar with ISE Ray Tracing Model

不均匀度85MW 约旦 Inhomogeneity 85MW, Jordan



越靠近边缘越亮：

散射光线较多

Closed to the edge is brighter means:

More diffuse light incoming

光线跟踪法应用实例 Appliance Exemplar with ISE Ray Tracing Model

结果85MW 约旦 Result 85MW, Jordan

- Specific Yield: 2,703 kWh/kWp
- 光线增益 BGopt = Grear / Gfront = 10.9%
- 组件增益 BGmod = (Grear * bf) / Gfront = 8.3%
- 系统增益 BGsys = Erear / Efront = (Ebifi – Emono) / Emono = 7.1%

光线跟踪法应用实例 Appliance Exemplar with ISE Ray Tracing Model

结果85MW 约旦 Result 85MW, Jordan

- Specific Yield: 2,703 kWh/kWp

- 光线增益 BGopt = Grear / Gfront = 10.9%

  系统几何设计 **System geometry**

- 组件增益 BGmod = (Grear * bf) / Gfront = 8.3%

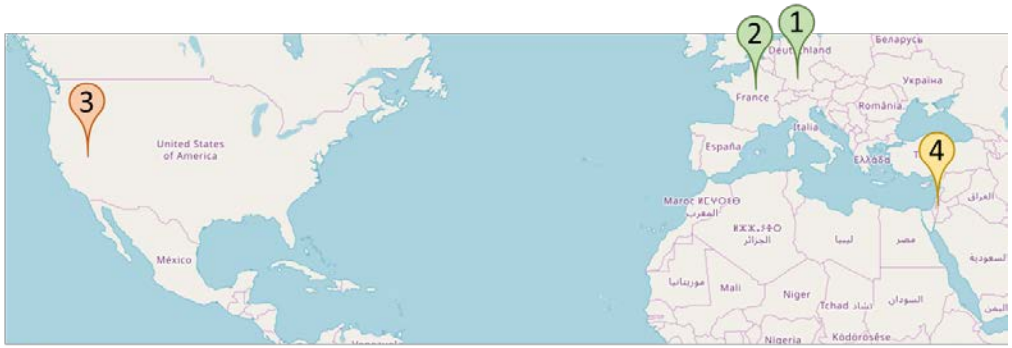
  组件特性 **Module characteristic**

- 系统增益 BGsys = Erear / Efront = (Ebifi – Emono) / Emono = 7.1%

  电气设计 **Electrical design**

模型验证 Model Validation

- 与法国电力共同合作项目 Joint project with EDF
- Results revealed on Sep. 26th 2018 at EU PVSEC, Belgium
- 法电与ISE的不同光伏系统 PV Installations from EDF and ISE

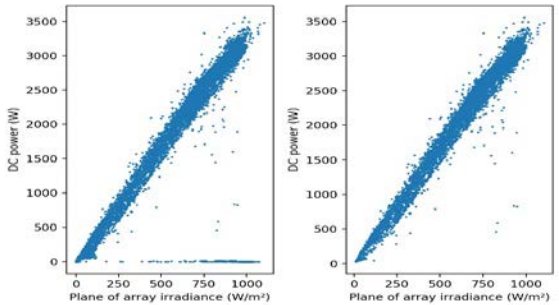


1. Single module with varying tilt in oceanic climate
2. Fixed-tilt installation in oceanic climate
3. Horizontal single axis tracking installation in desertic climate
4. Virtual fixed-tilt plant in Mediterranean climate

Source: M. Chiodetti et al., EU PVSEC, Belgium, Sep. 26th 2018

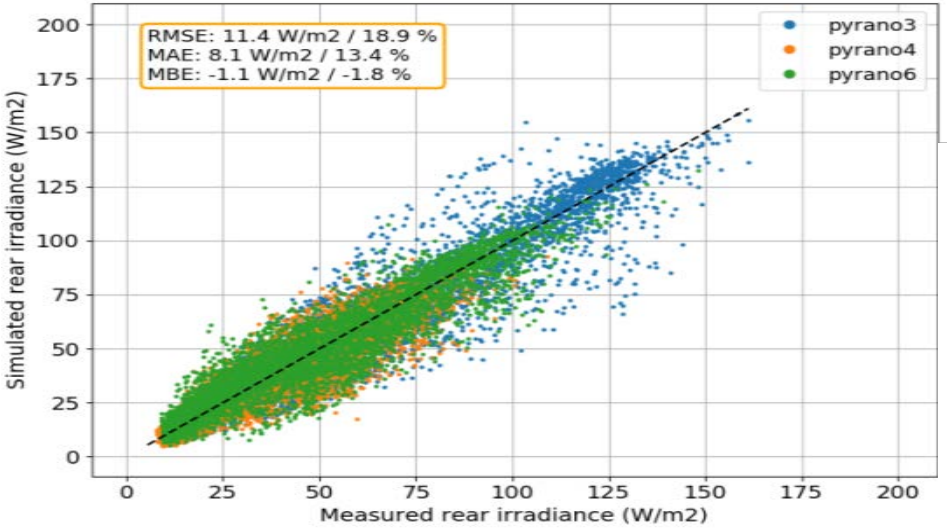
模型验证 Model Validation

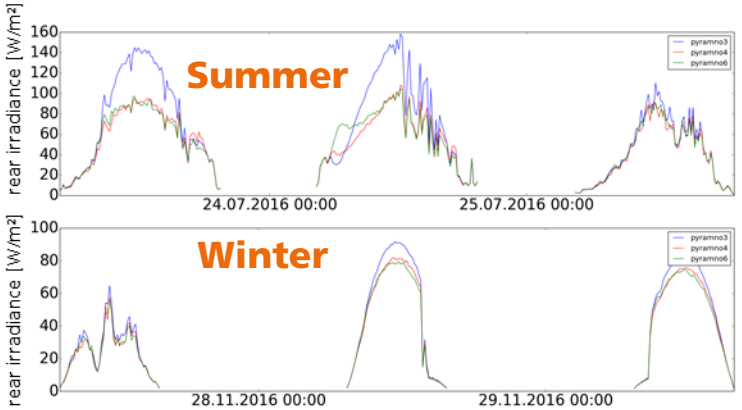
- 不同水平验证 On different level:
  - 辐照 Irradiance
  - 发电参数 Electrical value
- 监测数据包含 Monitoring at
  - 水平与反射辐照 GHI front and Albedo (horizontal)
  - 环境与组件温度 Ambient and module temperature
  - 直流测电流电压功率Current, voltage and power on DC side
- 数据筛选 Data Filtering



Source: M. Chiodetti et al., EU PVSEC, Belgium, Sep. 26th 2018

模型验证,法国:7个月 Model Validation, France: 7 Months
Irradiance measurement vs simulation

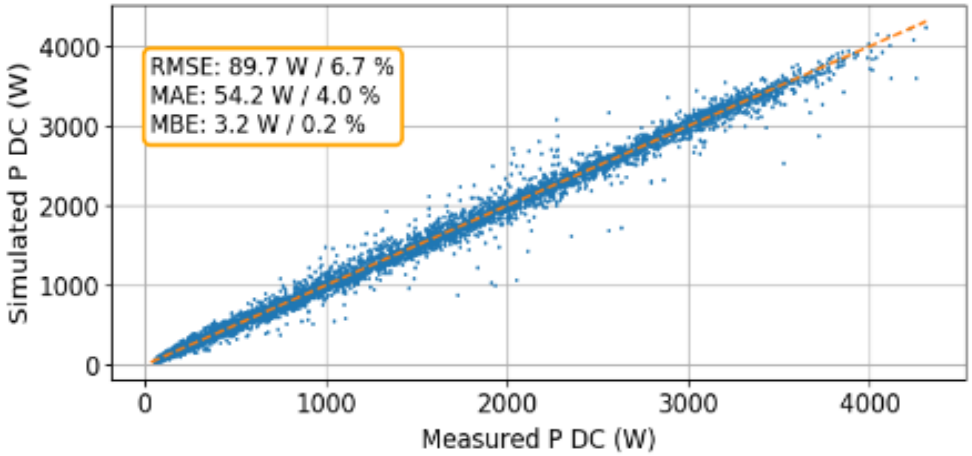


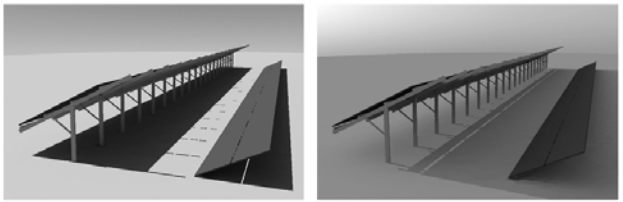


Source: M. Chiodetti et al., EU PVSEC, Belgium, Sep. 26th 2018

模型验证,法国:7个月 Model Validation, France: 7 Months
Power measurement vs simulation

- n-PERT modules
- fixed-tilt 30° with 50% GCR
- Albedo: 30%

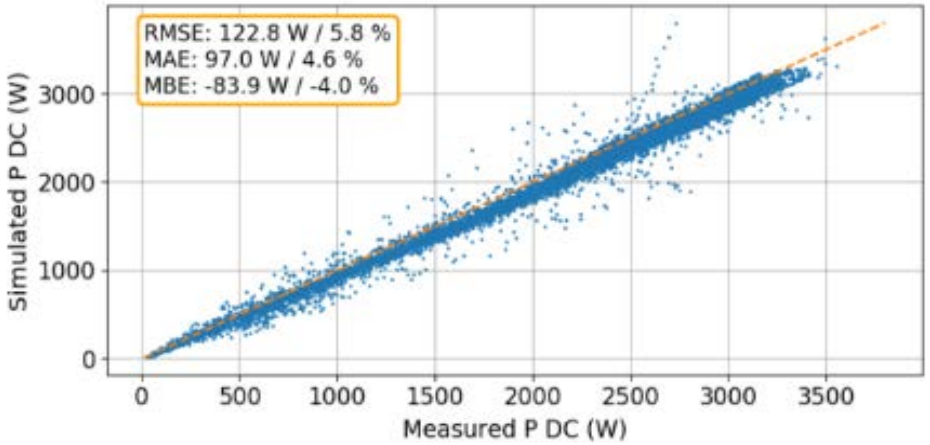




Source: M. Chiodetti et al., EU PVSEC, Belgium, Sep. 26th 2018

模型验证,加州:6个月 Model Validation, California: 6 Months
Power measurement vs simulation

- p-PERC modules
- Single axis tracker, with 35% GCR
- Albedo: 32%



Source: M. Chiodetti et al., EU PVSEC, Belgium, Sep. 26th 2018

结论

Summary

- 双面系统会有更高的发电量
- 发电模型可以有贴近单面模型的准确率
  - 均方根值低于7%
  - 平均偏差 ±4%
- 在解读双面增益时很重要的一定要了解数据背后的边界条件
- Bifacial PV systems may achieve high performance
- Simulation may reach similar accuracy as with monofacial systems
  - Root Mean Square Errors below 7%
  - Mean Bias Errors ±4%
- When interpreting the Bifacial gain, always pay attention to the boundary condition

结论

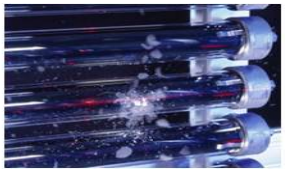
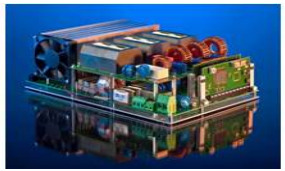
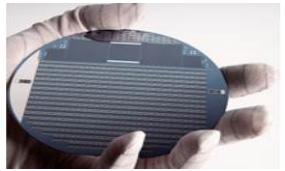
Summary

更进一步研究 Further Investigation

- 对比view factor模型 Comparison with models based on view factor theory
- 验证更多电站数据 Validation with more real system performance data
- 模型加强 Model improvement
  - 反照率的变动 Albedo variability
  - 双面的电气模型 Bifacial electrical model
  - 热建模 Thermal model
- 长期双面组件衰减 Long-term bifacial module degradation

谢谢您的参与!
Thank you for your attention

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