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User Experience with Module Performance Coefficients

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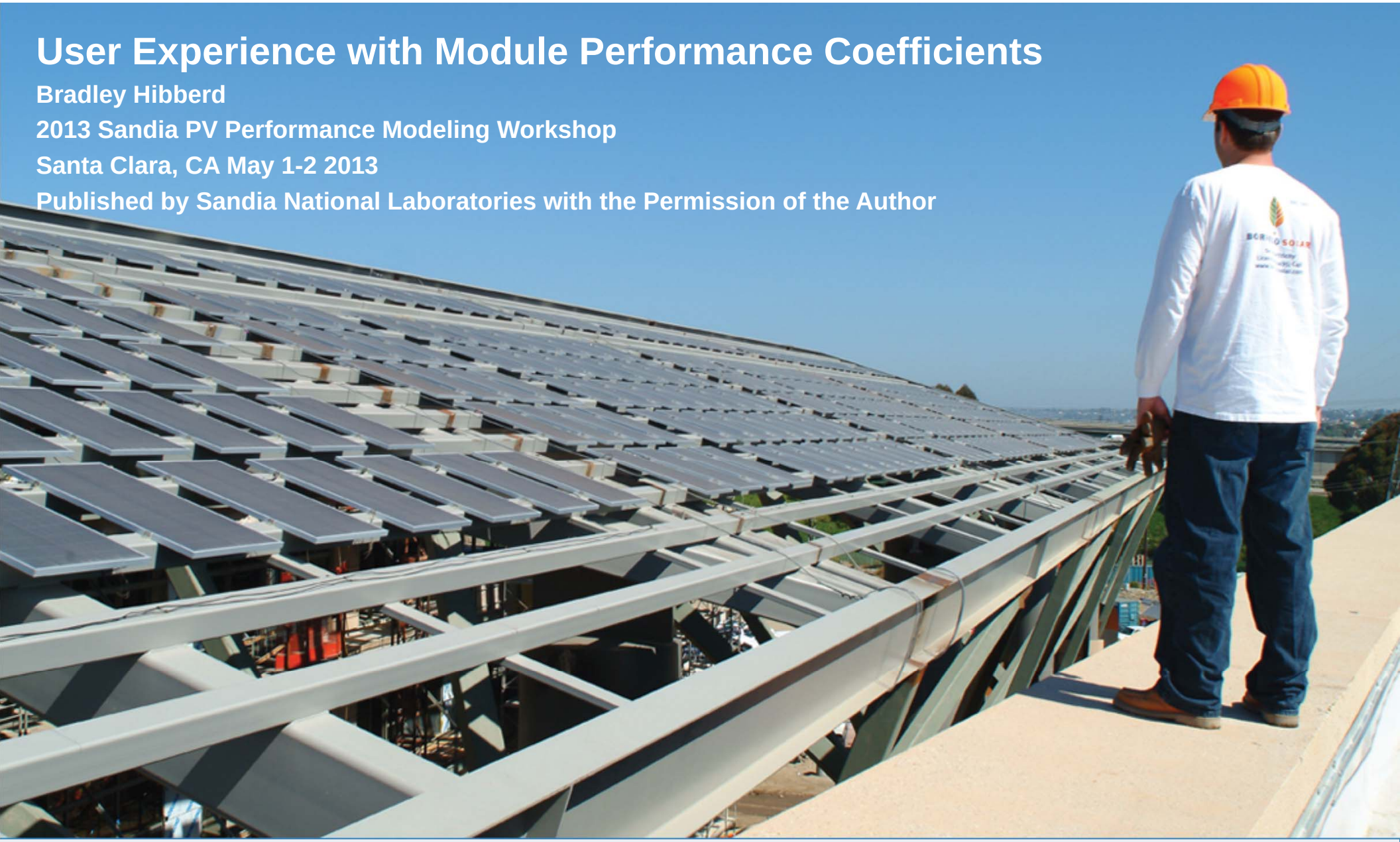


Uses of Performance Modeling (Using PVsyst)

- Performance Modeling for Projects
  - For energy generation and also for optimization of design.
- Product Evaluation – Relative Value of Module
  - Relate differences in performance to EPC price and hence module cost after adjusting for balance of system cost differences.
  - Create sample project or projects in PVsyst to model different modules.
  - Recently have seen an increase in module manufacturer supplied PAN files.
    - Range of supporting documentation of testing conducted and PAN file creation processes.
    - Accompanied by reports for light induced degradation, LID, tests and increasingly for angle of incidence modifier, IAM. These vary significantly and have significant impact on performance.
- Needed from Modeling Results?
  - An accurate representation of how each module will perform in the field.
  - If this is not consistent from module to module then the exercise is pointless, we may as well just value the module based purely on it's rated power at STC conditions.
  - Recent experience suggests significant variation from manufacturer/testing laboratory/engineering firm on at minimum the approach to defining the PAN file.

Which Module PAN File Should Be Used?

- Data Sheet Based
  - Based on information published on module data sheet.
  - This is some of the value of PVsyst in that models can be run based solely on this information.
  - Generally acknowledged to be conservative, particularly in terms of low irradiance efficiency
  - Could be modified to reflect the reduction in efficiency at low irradiance sometimes published on data sheet values.
  - How representative are the data sheet values that are the inputs to this file? How many modules are tested? When in the manufacturing cycle?
- Manufacturer Supplied
  - Based on testing by manufacturer, laboratory or engineering firm and a process for creating PAN file from the test data.
  - In theory is a better representation of that module performance.
  - Generally realize significantly more production, on the scale of several percent.
  - What testing is conducted? How many modules? How are they selected? What is the process for creating PAN file from test data? Is it consistent from manufacturer to testing laboratory to engineer?

User Experience with Module Performance Coefficients

Module Details/Difference Between Manufacturer Supplied and Data Sheet PAN Files

	MODULE A	MODULE B	MODULE C	MODULE D	MODULE E
Technology	Poly Si	Poly Si	Poly Si	Mono Si (P type)	Poly Si
# Cells	72	72	72	60	72
V_{oc}	0.0%	0.0%	1.2%	-0.8%	0.4%
V_{mp}	0.7%	0.0%	-1.1%	0.0%	-0.2%
I_{sc}	-1.1%	0.0%	1.6%	1.4%	2.7%
I_{mp}	-0.6%	0.0%	1.2%	1.4%	0.1%
Temperature Coefficient P_{max}	0.0%	0.0%	-16.3%	-11.1%	4.4%
Temperature Coefficient I_{sc}	0.0%	30.4%	3.0%	-2.5%	0.0%
Temperature Coefficient V_{oc}	15.2%	15.4%	-9.8%	10.2%	9.4%
Efficiency Reduction @ 200W/m^2	-37.7%	-62.3%	-79.0%	-72.4%	-69.7%
R_{series}	47.8%	376.5%	404.3%	536.2%	352.4%
R_{shunt}	16.7%	0.0%	20.5%	-14.3%	185.7%
R_{shunt}; G=0	-43.0%	-50.0%	-51.6%	-28.6%	185.7%
Light Induced Degradation	1.4%	1.0%	0.82%	POST LID	2.0% ASSUMED

Observations on Manufacturer Supplied PAN Files

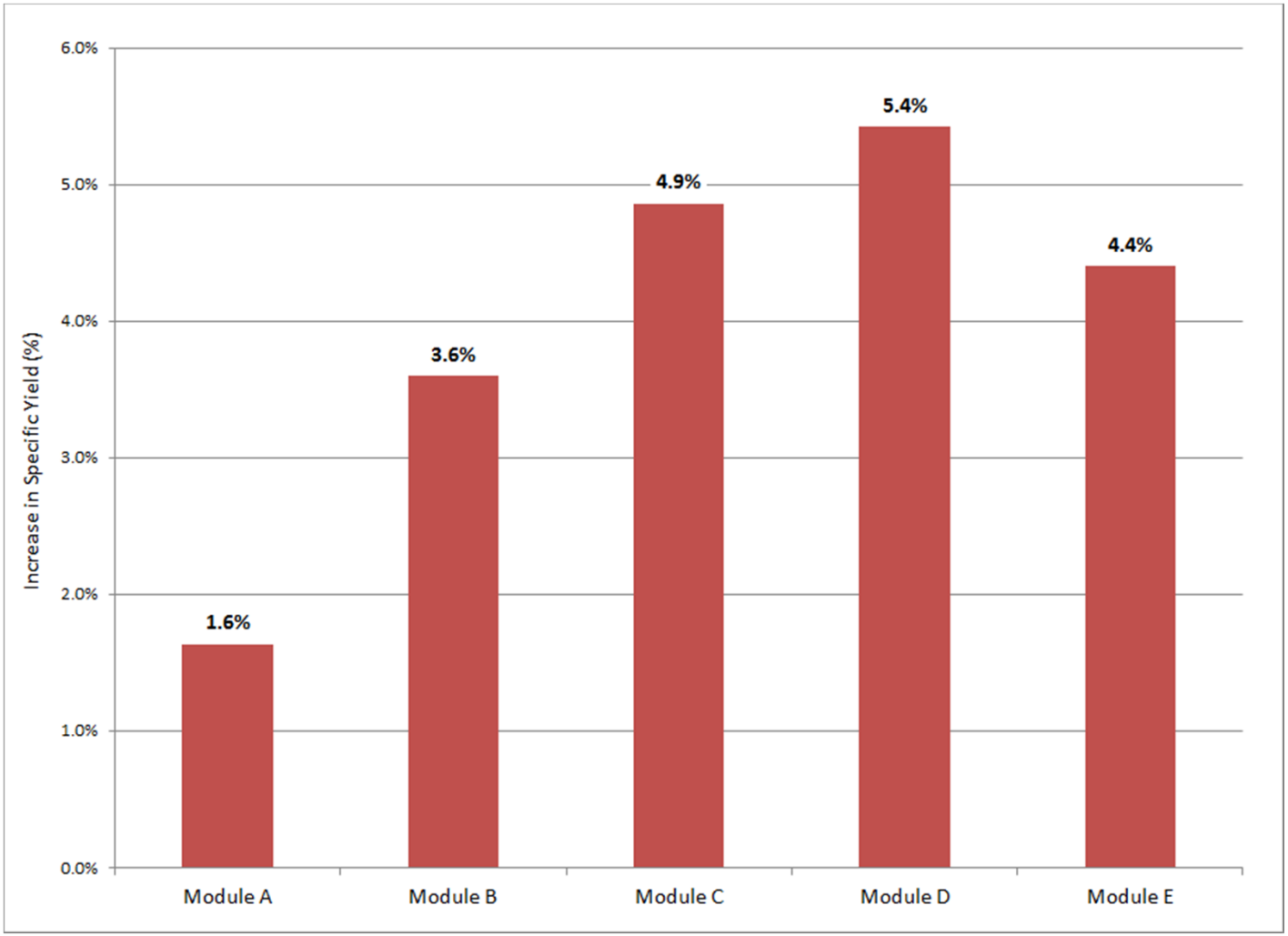
- Module Electrical Data and Performance Coefficients
  - Varying approaches to matching published values from data sheet and modifying performance coefficients.
  - Low irradiance performance indicated on the data sheet is not matched by that in the manufacturer supplied PAN files.
  - What is the relationship between tested modules and PAN file created in terms of nominal power?
  - How were the modules supplied to the testing facility? Random sampling or selected?
- Light Induced Degradation, LID
  - LID should be included in the modeling.
  - What testing is performed to characterize LID? How many hours of exposure?
    - Range: 5.5kWh/m^2 to 140kWh/m^2, resulting in LID from 0.5% to 2.3%.
  - Should the PAN file be generated based on post LID?
- Other Issues
  - Manufacturer recommendations for PVsyst modeling are often inaccurate, e.g., inputs of 0% for mismatch and module quality adjustment
  - Incident Angle Modifier IAM: varying approaches and results to performing this.

PVsyst Modeling Inputs

- PVsyst Version: V5.65
- Model Setup and System Design
  - Site and Weather Data: Boston Logan TMY3
  - Inverter: SMA SC500HE-US, OND file with 3 efficiency's defined.
  - Orientation: Unlimited sheds array facing south at 25° using "electrical effect" for shading.
  - System Design: Inverter loaded to ratio of 1.2, modules oriented in landscape in columns of 4.
- Loss Parameters
  - Thermal: Constant 29.0 W/m2K; Wind 1.2 W/m2K/m/s
  - Ohmic Losses: DC 2.0%, AC 0.5%
  - Transformer Losses: Core 0.2%, Resistive 1.5%
  - Module: Quality: varies per module; mismatch 0.5%
  - Soiling: 1% annual loss.
  - IAM Losses: Standard ASHRAE profile

User Experience with Module Performance Coefficients

Increase in Specific Yield with Manufacturer PAN Files Compared to Data Sheet File

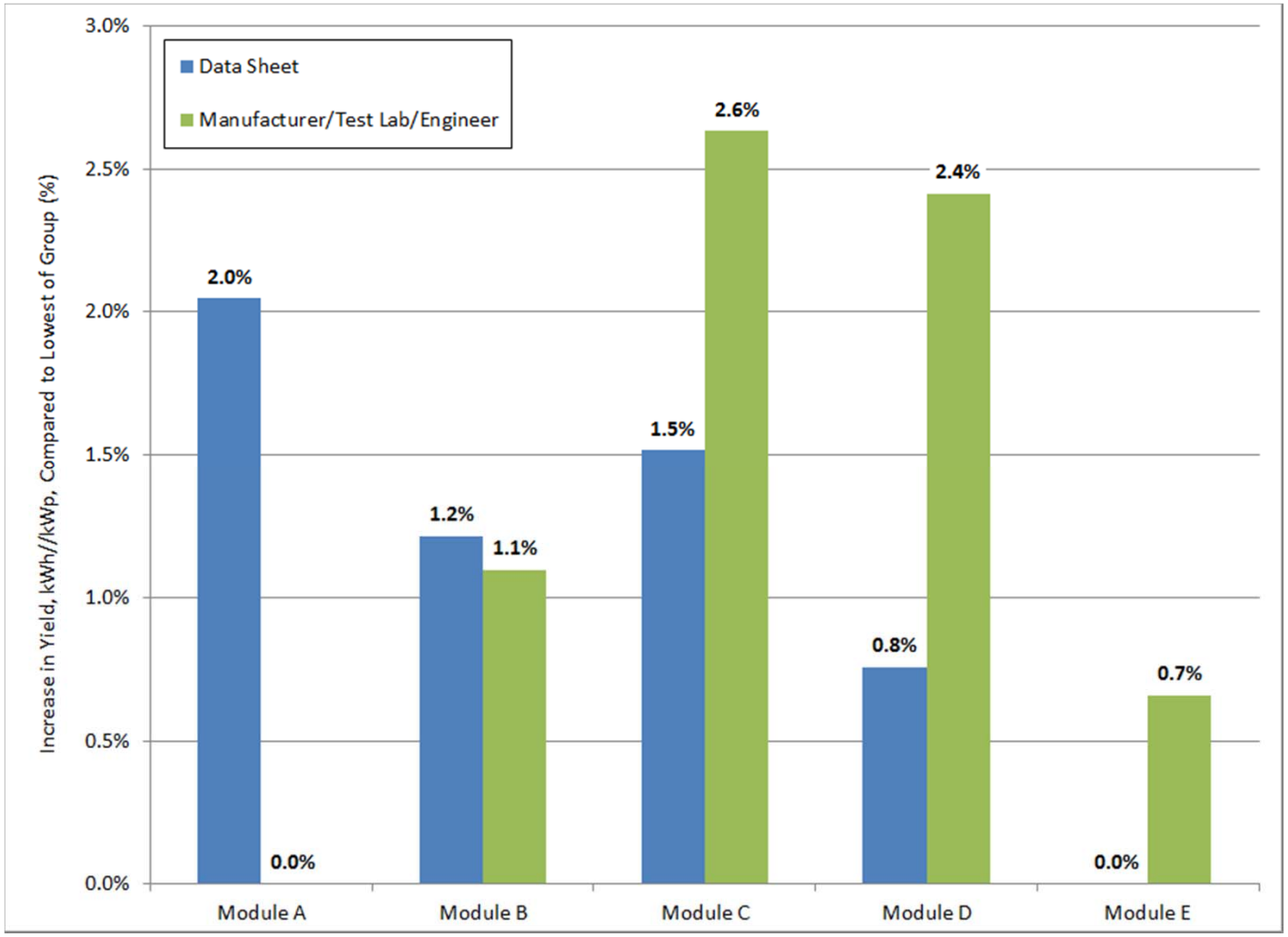


Notes

- Low Irradiance Efficiency
  - Average 64% reduction.
  - Maximum 80% reduction, Module C.
  - Minimum 38% reduction, Module A.
- Temperature Coefficient P_{max}
  - Average 5% reduction.
  - Maximum 16% reduction, Module C.
  - Minimum 0% reduction, Module A & B.
- Are these effects real? Can we rely on them?
  - Is Module A conservative?
  - Is Module C aggressive?
  - What will we see in practice?

User Experience with Module Performance Coefficients

Difference in Specific Yield Between Modules as a Function of PAN File



Notes

- Standard File
  - Module E lowest yield.
  - Other modules 0.75% to 2.0% higher yield. Value up to $0.05/W.
  - Temperature coefficients approximately constant.
  - Low irradiance performance is driver.
- Manufacturer File
  - Module A lowest yield.
  - Other modules 0.65% to 2.6% higher yield. Value up to $0.065/W.
  - Temperature coefficient and low irradiance is driver.
- Which PAN file should be used?
- Consistency across vendors?

Summary – What Is Needed

- Reliability of modeling results, particularly in a relative sense.
- If this is not possible, the manufacturer supplied PAN files are devalued.
- PAN files to be created based on consistent testing and creation methodology.
- A standard that can be used across testing labs and engineering firms.
- This is not a statement on how this should be done, rather it's a call for that standard.
- Similarly, LID and IAM testing should be standardized.