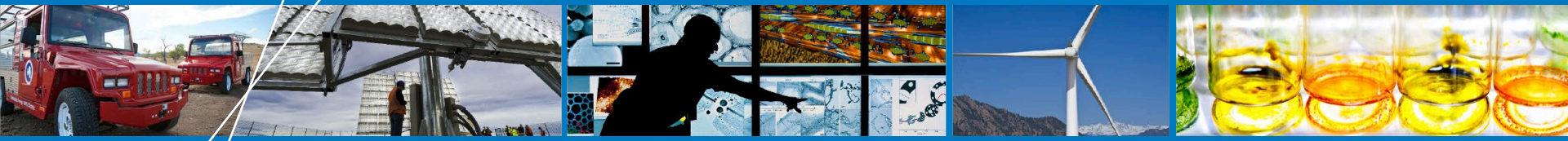
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Opportunities and Challenges in the Development of Smart PV Systems



Trina State Key Laboratory
2015, Changzhou, China

Chris Deline

June 25-26, 2015

NREL/PR-5J00-64525
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Roadmap

- About NREL
- Overview of Distributed MPPT (DMPPT) in PV
- Performance benefits of DMPPT
- Maxim smart modules - performance

NREL is located in Golden, Colorado, and is:

- Part of the Department of Energy's laboratory system
- Focused on renewable energy, including Solar, Wind, Bioenergy and Grid Integration
- Operated as a government research facility, and also as a user facility for industry testing and R&D

Operations began in 1977 as the Solar Energy Research institute, but quickly expanded to include other renewables including wind, hydro and biomass.

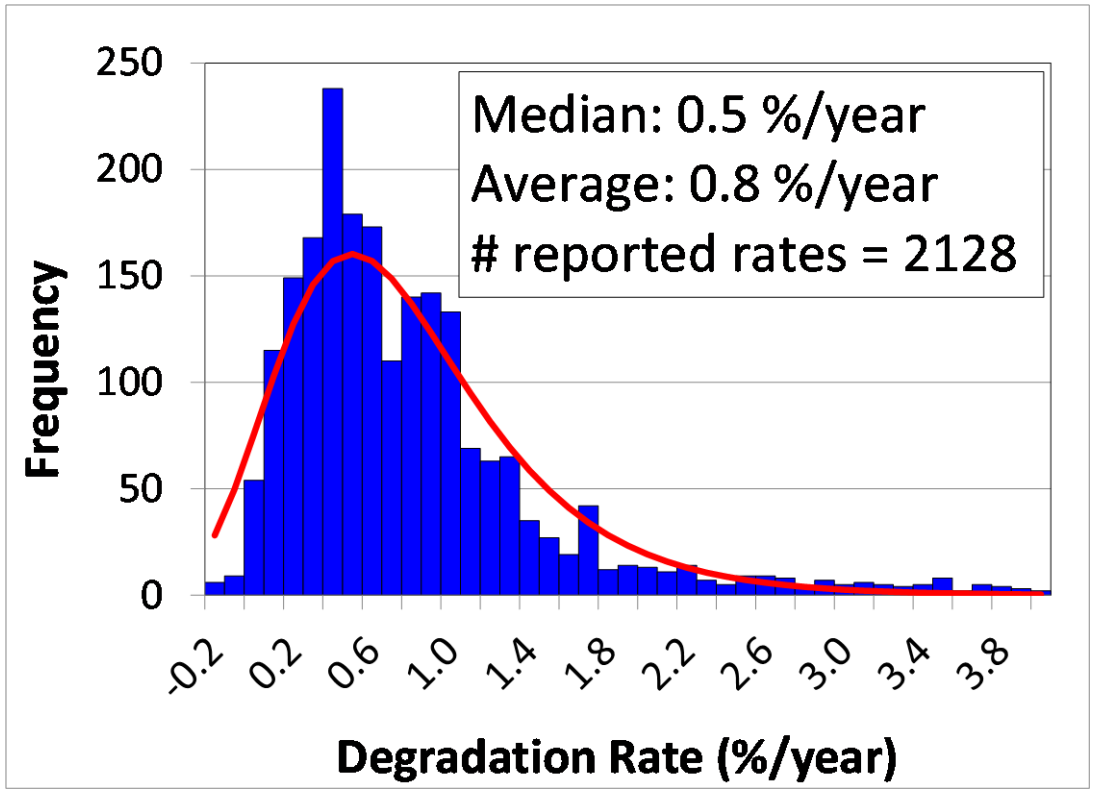
Current NREL statistics include:

- 1720 full employees and 678 part-time researchers, interns, and contractors
- $371M budget (2013)
- 57 R&D 100 awards (top 100 technologies of the year)

The PV performance and reliability group at NREL focuses on outdoor field performance / reliability and indoor accelerated test and characterization:

- Accurate PV performance characterization and modeling
- PV degradation rate and failure mode assessment
- US and international standards for reliability and quality

Statistical analysis of degradation rates

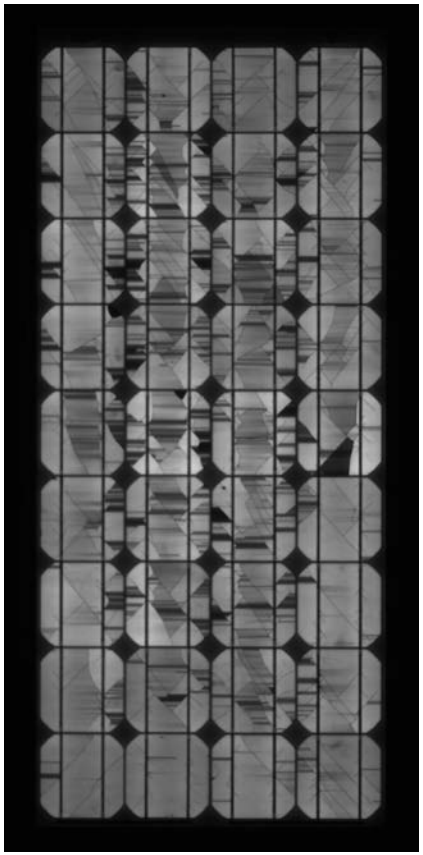


Literature data show statistical distribution of degradation rates: Majority meet performance warranty

Jordan, Prog. Photovolt: Res. Appl. 2013; 21:12–29. DOI: 10.1002/pip.1182

Three types of failures in the laminate

- **Broken ribbons**
  - Testing is much like testing a paper clip
  - Cyclic mechanical stress gives very high acceleration
- **Broken solder bonds**
  - Time-dependent response to stress increases time needed to induce damage
  - Acceleration factors are smaller and harder to quantify, but testing is effective; 200-2000 cycles?
- **Cracked cells**
  - Power loss occurs if cracked piece becomes disconnected
  - Problems are uncovered by mechanical load followed by thermal cycling

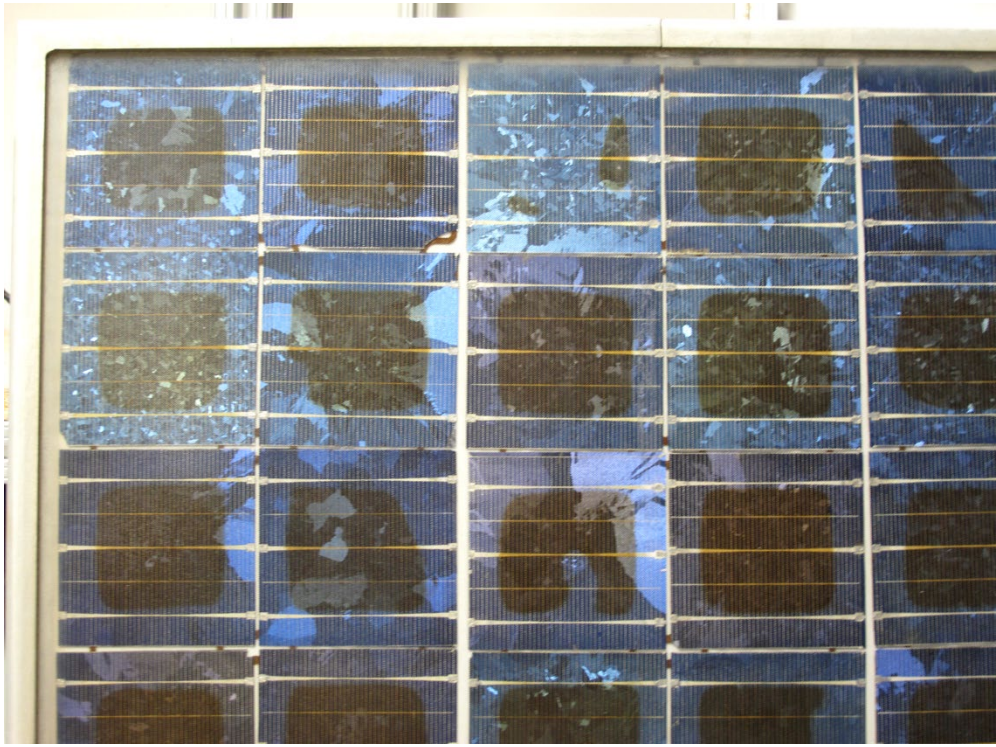


We know how to detect design flaws that cause these failures!

But, we'd like to detect the problems faster and nondestructively!

Encapsulant Discoloration

- Discoloration may be primary source of degradation (Isc loss)
- Competing reactions cause discoloration and bleaching
- What if bleaching is accelerated more than discoloration? *High acceleration factors may result in "wrong" answer*



Chemistry of polymers can be complex
What to do?
Be relevant by using high acceleration BUT, be scientific by defining degradation kinetics and doing parallel tests with low acceleration factors!

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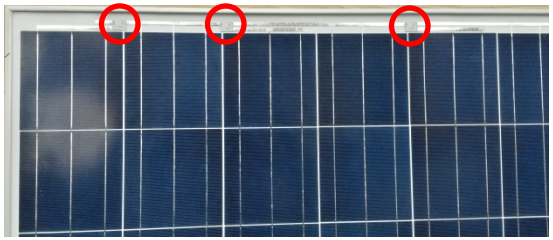
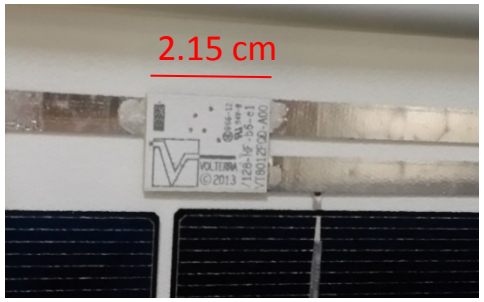
Examples of Distributed MPPT products





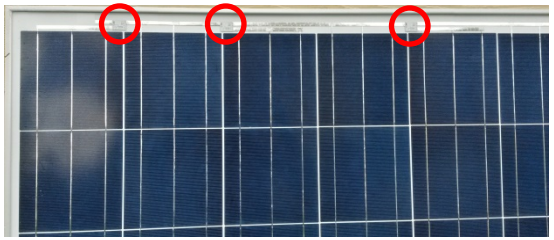
Frame – attached (Enphase Energy)

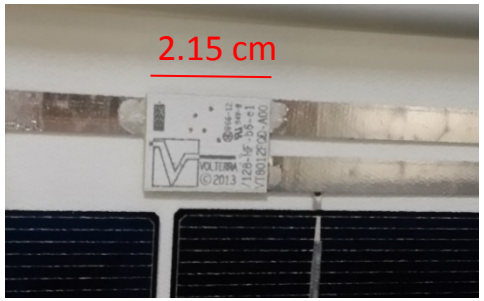
J-box embedded (Tigo Energy)

Laminate embedded (Maxim Integrated)

Credit: Enphase Energy, Tigo Energy, Maxim Integrated

Examples of Distributed MPPT products





Frame – attached (Enphase Energy)

J-box embedded (Tigo Energy)

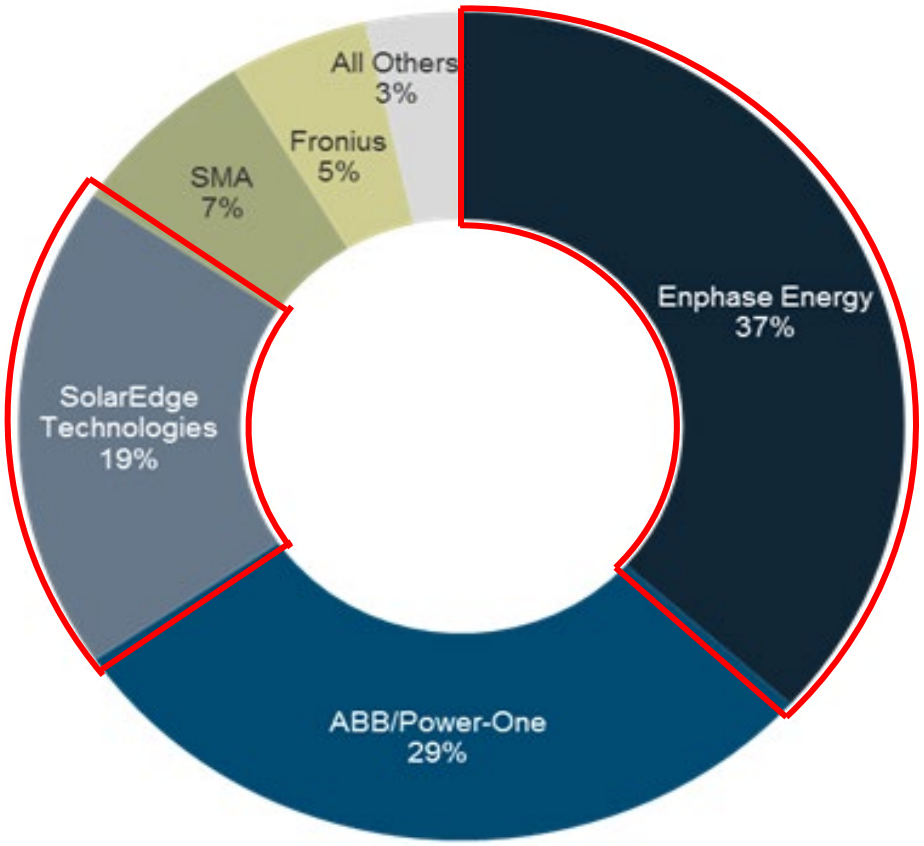
Laminate embedded (Maxim Integrated)

DMPPT = MLPE, microinverter, power optimizer…

Credit: Enphase Energy, Tigo Energy, Maxim Integrated

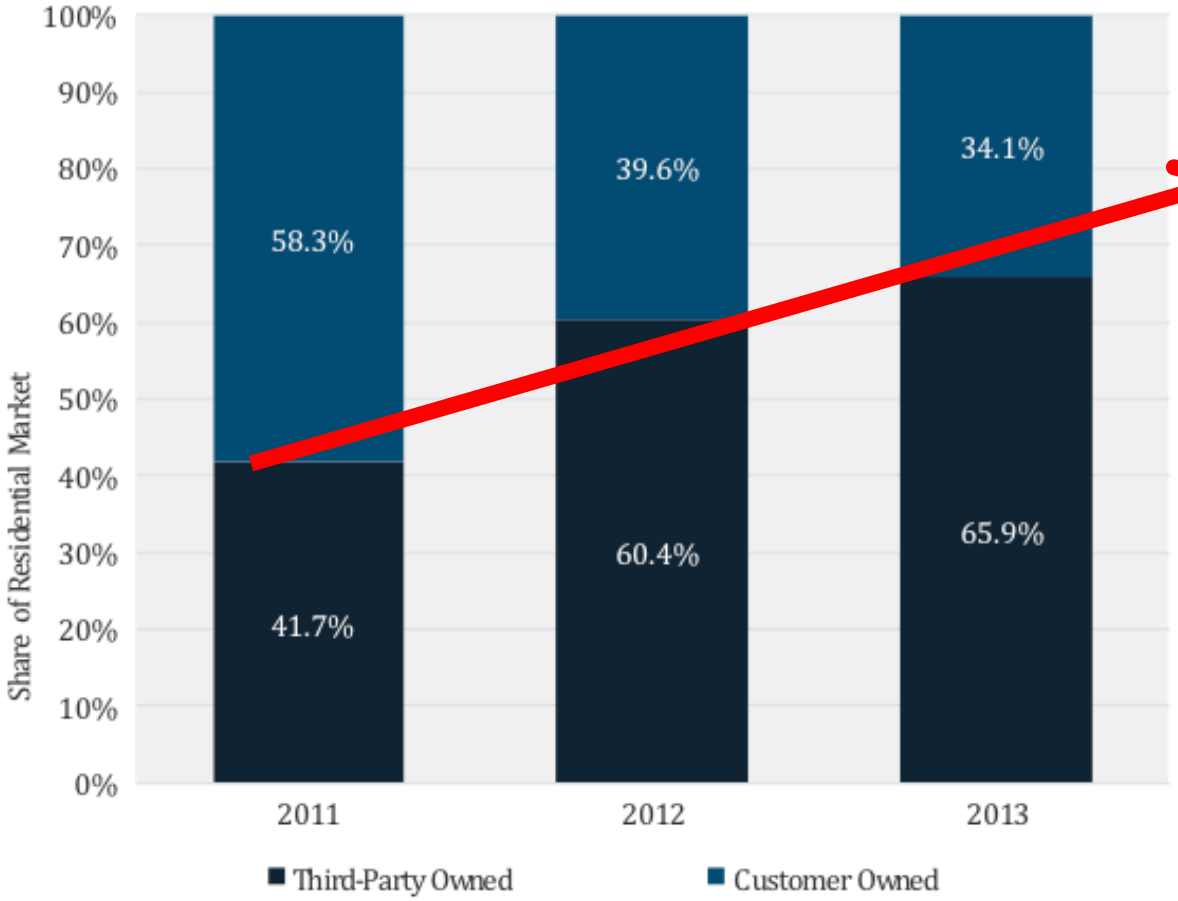
US residential market (1H 2014)

DMPPT market share: 56%



Source: GTM Research U.S. PV Leaderboard, Q2 2014

US residential market – 3rd party ownership



3rd-party-owned in 2014 : 68%

Source: GTM Research U.S. Residential Solar Financing 2014-2018

DMPPT pro/con

Pro:

- Flexibility of design
- NEC 690.12 safety
- Data monitoring
- Shade performance
- Warranty

Con:

- Cost
- Efficiency (maybe)
- More potential points of failure
- O&M concerns

NEC 690.12 (2014)

Code requires rooftop PV conductors greater than 10’ from the array to be de-energized in event of emergency

Compliance options:

Remote relays

Roof-mounted inverters

Microinverters and Power Optimizers

Credit: Midnite Solar, SMA, Tigo

Other emerging inverter trends:

- California Rule 21 (grid support capabilities for PV inverters)
- Storage capabilities for utilities without net metering, or with time-of-day pricing
- NEC 690.12 (2017): proposed module-level shutdown

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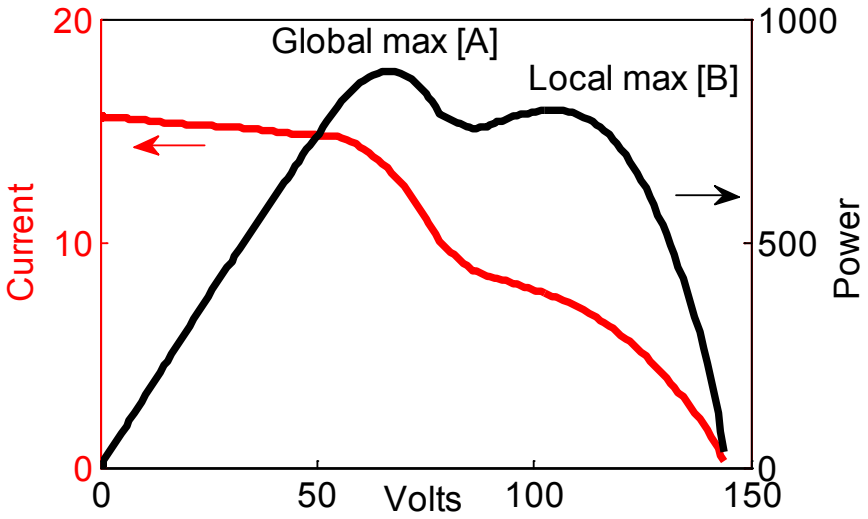
Recoverable vs. Non-recoverable loss in PV

Partial shading leads to power loss from reduced irradiance (non-recoverable) and panel mismatch (recoverable)

The better the peak-power tracking (MPPT) granularity, the higher the recoverable power

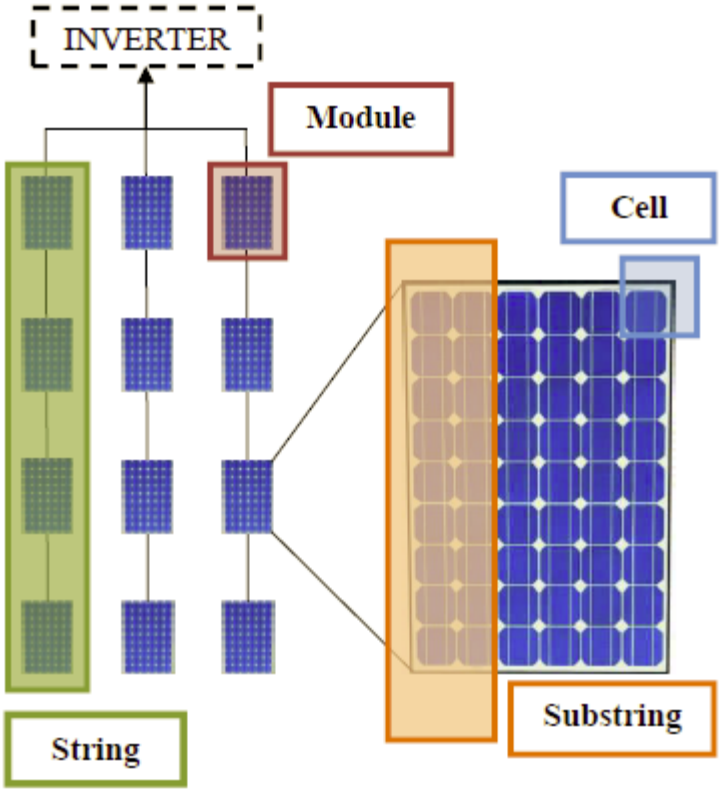


Mismatched panels in a series string. Either bypass diodes are turned on in the shaded panels (point [A]) or all panels operate at a low current (point [B])

C. Deline, B. Marion, J. Granata, S. Gonzalez. *A Performance and Economic Analysis of Distributed Power Electronics in Photovoltaic Systems*. NREL Report No. TP-5200-50003. Golden, CO: National Renewable Energy Laboratory, December

Overview of Distributed MPPT

Finer peak-power tracking granularity leads to reduced mismatch



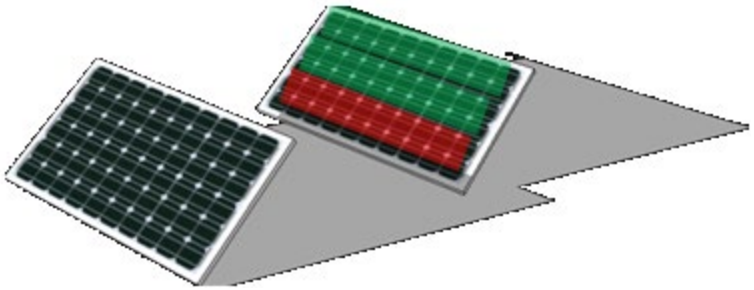
Annual performance improvement under heavy shade

+2%	+8%	+9%	+12%
String	Module	Submodule	Cell

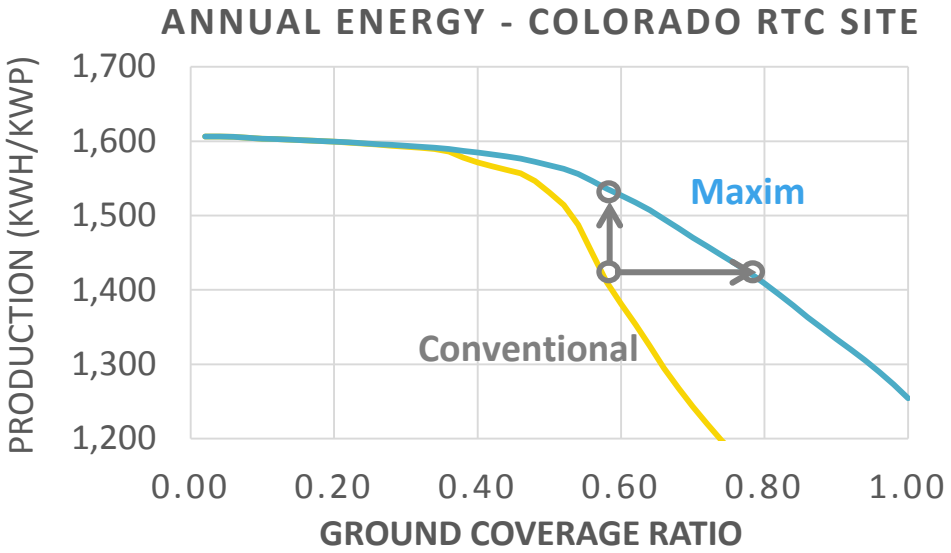
MPPT Granularity

S.M. MacAlpine, M.J.Brandemuehl, R.W.Erickson, "Potential for power recovery: simulated use of distributed power converters at various levels in partially shaded photovoltaic arrays," in Proc. PVSEC 2011.

Sub-module power conversion



*Mismatch occurs **within** the module



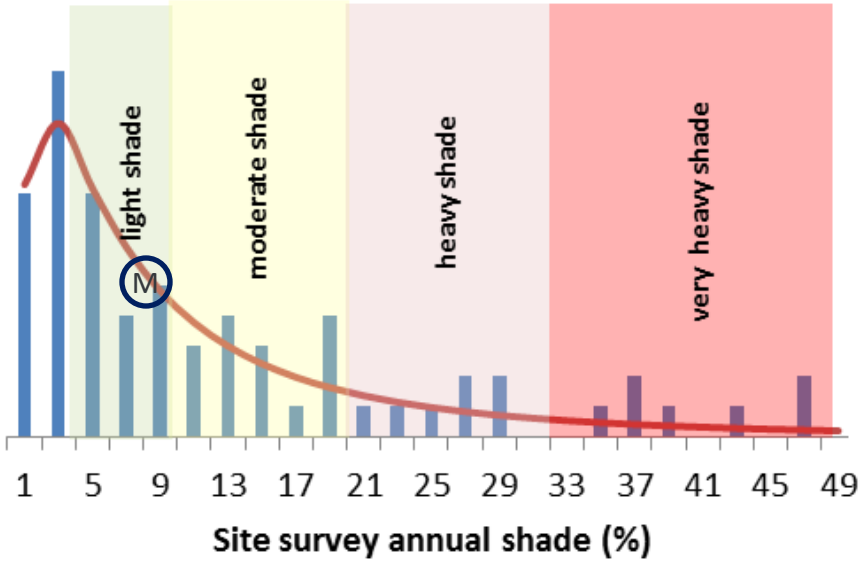
Sub-module DC-DC converters:

- Enable 10-20% tighter row pitch, -or-
- 1-3% more energy / panel at the same row pitch

C. Deline et al., "Evaluation of Maxim Module-Integrated Electronics at the DOE Regional Test Centers", 40th IEEE Photovoltaic Specialists Conference, Denver, CO, 2014

Shading Survey gives real-life conditions

Survey of >60 residential installations provides distribution of **shade extent**

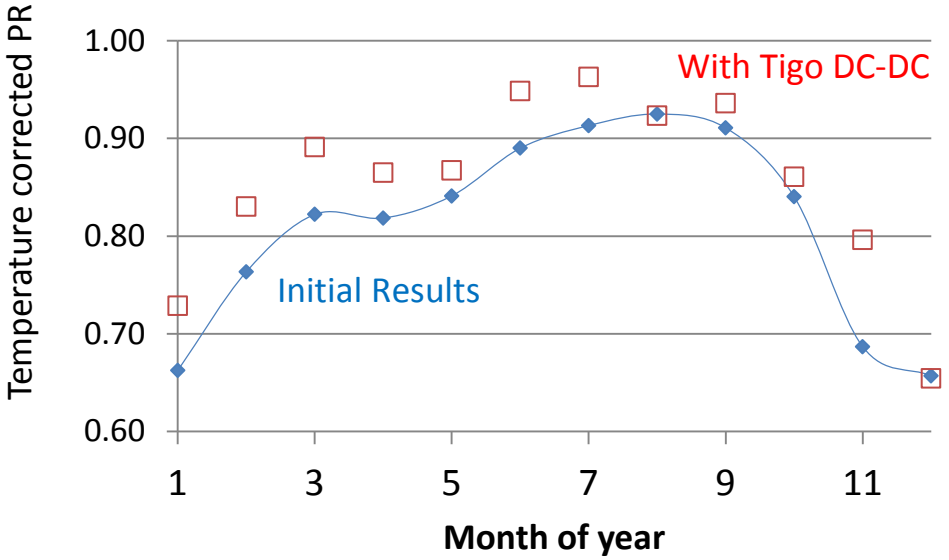


Deline, C., Meydbray, J., Donovan, M. (2012) NREL Report No. TP-5200-54876

Imaging tool shows shade obstructions for residential rooftops

Validation: before and after Power Optimizers

Monthly performance for 3 years



*5.8% more energy with module-level MPPT. 30% shade recovery

Hanson A, Deline C, MacAlpine S, Stauth J, Sullivan C, "Partial-Shading Assessment of Photovoltaic Installations via Module-Level Monitoring", IEEE Journal of Photovoltaics, **4** 1618-1624, 2014

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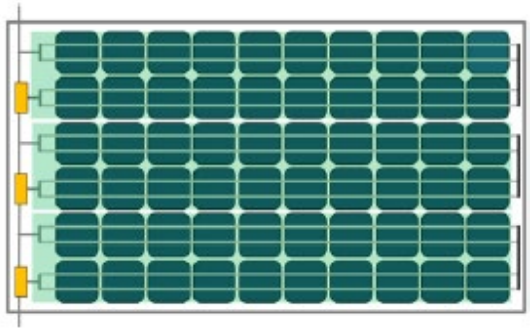
Maxim installation at FSEC

- Florida site uses VT8024 modules
  - 3 converters / module
- Performance data still coming on-line

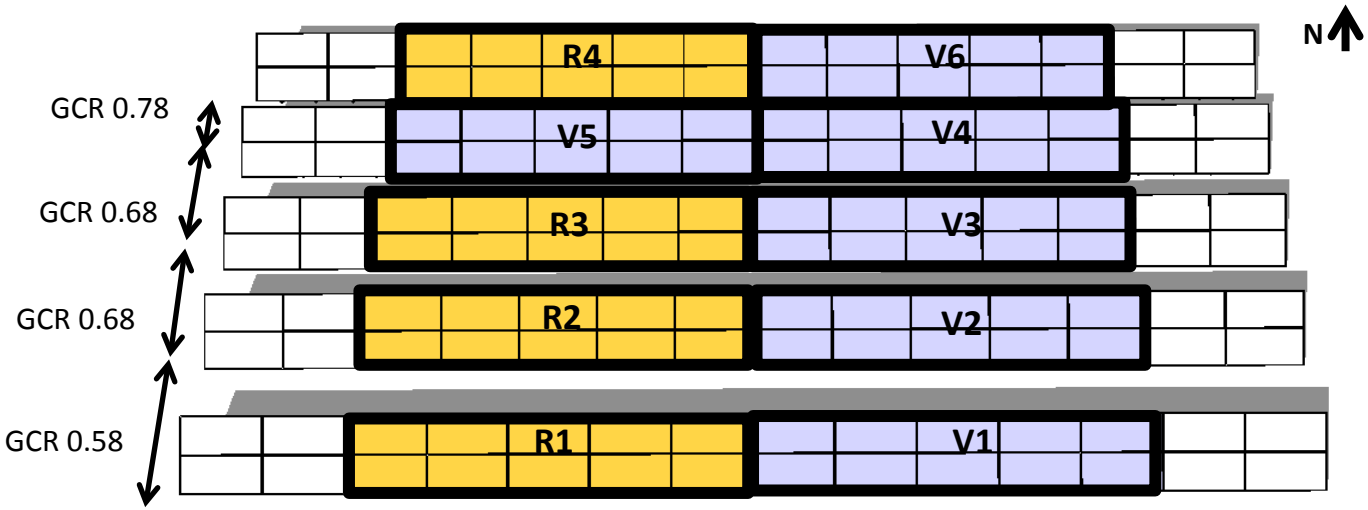


Maxim VT8024 module –for landscape deployment. One chip per 24 cells

Credit: Maxim Integrated

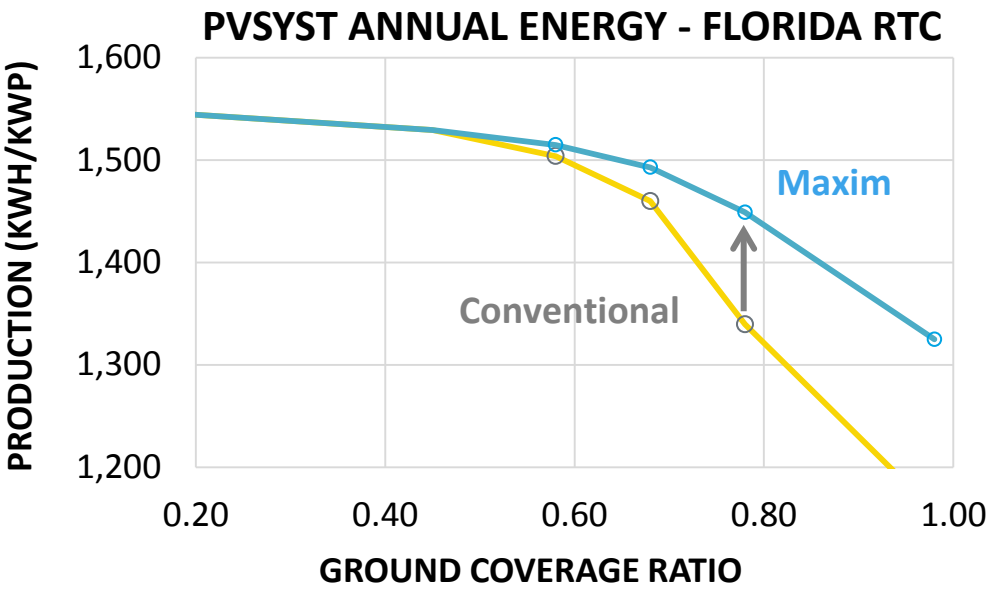
FSEC installation particulars

- Side by side Maxim panels (blue) with Conventional (yellow)
- 3 row spacings



FSEC system: performance model

- PVsyst models predict performance gain up to 8% at tight spacing
- Or increase packing density 10-20% for the same shade loss



Summary

- Embedded power electronics promise to reduce cost and increase MPPT granularity

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- US rooftop PV is moving to DMPPT for ease of design and increased safety
  - Rapid DMPPT acceptance, string inverter decline

Summary

- Embedded power electronics promise to reduce cost and increase MPPT granularity
- US rooftop PV is moving to DMPPT for ease of design and increased safety
  - Rapid DMPPT acceptance, string inverter decline
- Sub-module MPPT (Maxim) can improve performance and increase packing density for large un-shaded PV systems using low-cost converters

Questions?

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Acknowledgments

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