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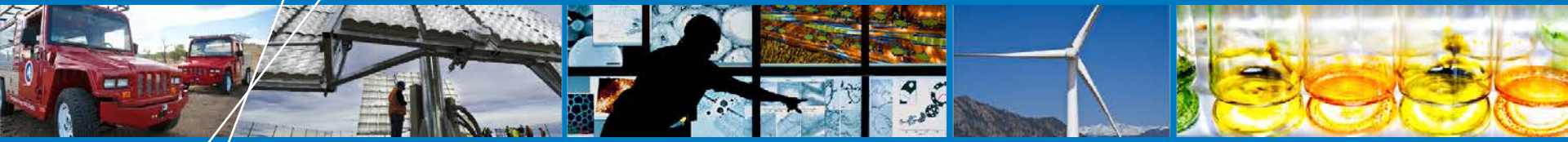
Distributed power electronics for PV systems



National Renewable Energy Laboratory's EPRI PV Technology Seminar

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12/15/2011

NREL/PR-5200-54183

Overview

- Introduction to PV power electronics
- Types of mismatch in PV systems
- Performance improvement from distributed electronics
- Market share and other considerations

Introduction – Distributed power electronics

- **Per-module electronics (DC-DC, µinverter) reduce mismatch loss**
- Each device tracks individual module max power point.
  - Decouples the panel voltage & current from the rest of the string
  - Monitoring capability
  - Safety, anti-theft

Credit: Enphase

Credit: National Semiconductor

Credit: Tigo


Credit: Solar Edge

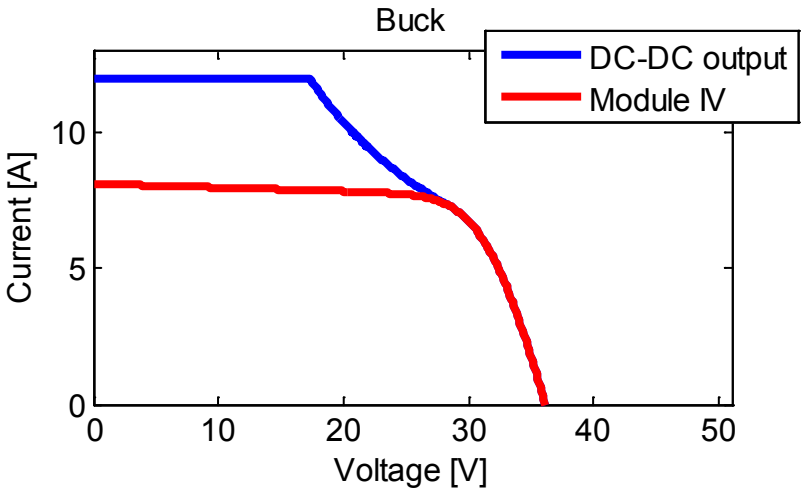
How DC-DC converters work

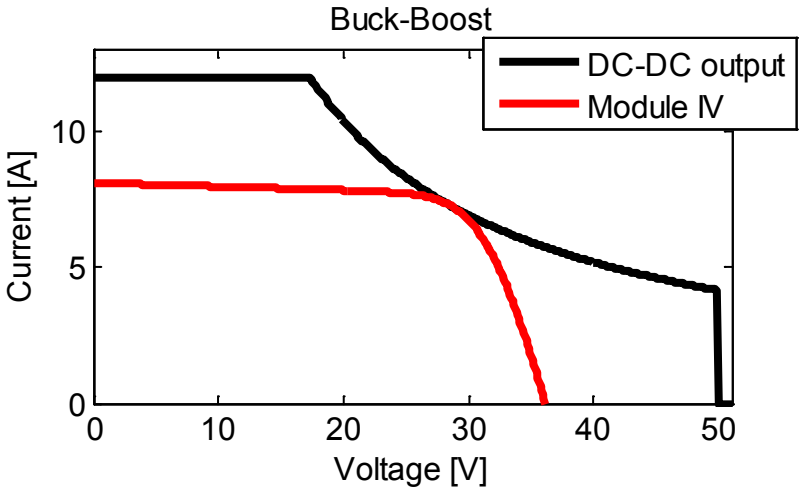
The output of a DC-DC converter is a constant power curve with voltage and current upper limits.

Impaired modules have their current boosted to match I_{mp} of unshaded modules.

With buck-boost devices, voltage of unshaded modules can be boosted to match parallel string voltage.

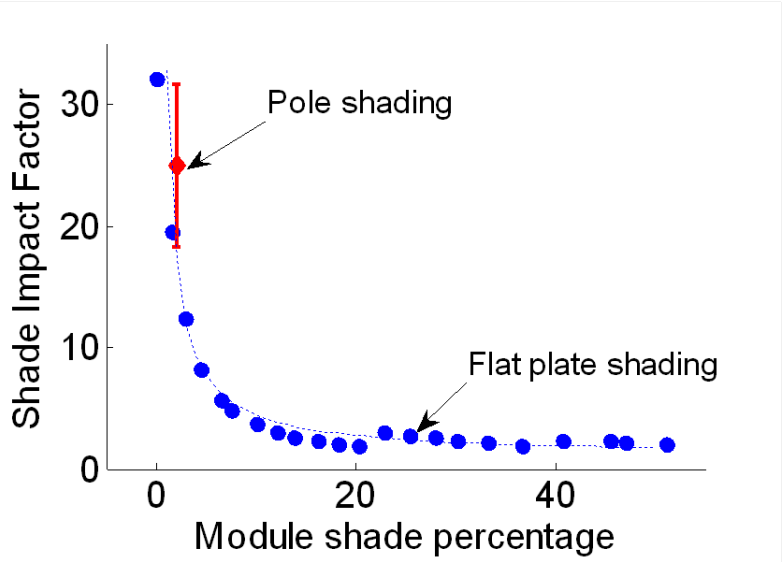
Note that device efficiency and insertion loss may offset gains





Introduction – Impact of Shade

- Shade impact depends on module type (fill factor, bypass diode placement), severity of shade, and string configuration.
- Power loss occurs from shade, also current mismatch within a PV string and voltage mismatch between parallel strings.
- Power lost is greater than proportional to the amount of shade on the system



'Shade Impact Factor' (ratio of power lost to area of shade) for a single module in a single string PV system [1]

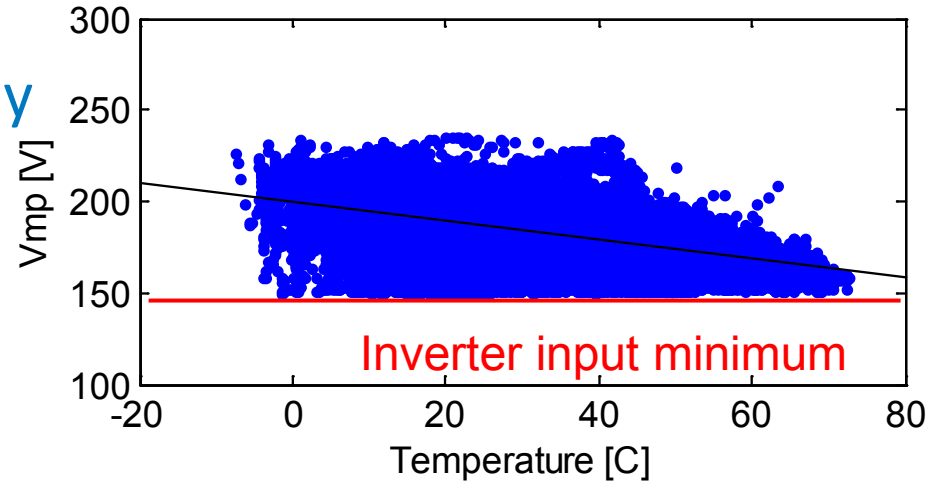
[1] C. Deline, IEEE PVSC, 2009

Introduction – Other sources of mismatch

Other types of mismatch can impact system performance:

- Soiling (dirt accumulation, bird droppings, snow build-up)
- Orientation of panels on different roof planes
- Distribution of panels' Imp rating (manufacturers typically bin to 2%)
- Differential aging
- Inverter voltage limits

System with varying module orientation



Inverter Vmp clipping due to high temperature and partial shade

Example mismatch losses

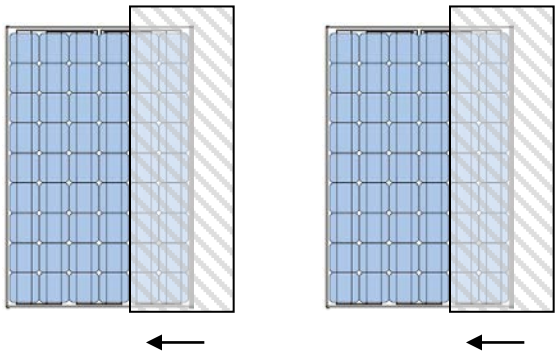
Type of mismatch	System loss (est)	Potential DC-DC gain*	Ref
Residential roof shade, 1 string	5-15%	+15-20% of loss	[2]
Residential rooftop shade – multiple strings	5-20%	+20-30% of loss	[2]
Commercial system with inter-row shading	1-5%	+30-40% of loss	[3]
Residential orientation mismatch , 1 string (East-West)	5-20%	+100% of loss	[4]
Imp distribution mismatch	0.2 - 1%	+100% of loss	[3]
Soiling – CA and Southwest US	1.5 – 6.2%	+15-40% of loss	[5]

**Not accounting for device efficiency or diode insertion loss*

[2] C. Deline, IEEE PVSC, 2010
[3] C. Deline et al, NREL technical report TP5200-50003
[4] S. MacAlpine, ASME, ES2009
[5] A. Kimber, IEEE Conference on PV energy conversion, 2006

Estimates of performance improvement from PV power electronics

Side by side comparison, 8kW systems - one with micro-inverters, one with a string inverter [7]

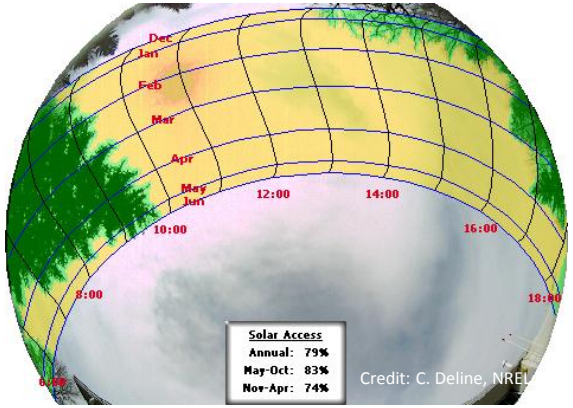


4%-12% performance improvement

CAD shading simulation [6]

4%-8% performance improvement

Site survey based simulation [3]



3%-6% performance improvement

[3] C. Deline et al, NREL technical report TP5200-50003

[6] S. MacAlpine, EUPVSEC, 4AV.3.15, 2011

[7] C. Deline et al, "Partial Shading Testbed for PV-Integrated Power Electronics Operating Procedure - Draft"

Current market share of micros and DC-DC

Majority of sales are for residential systems

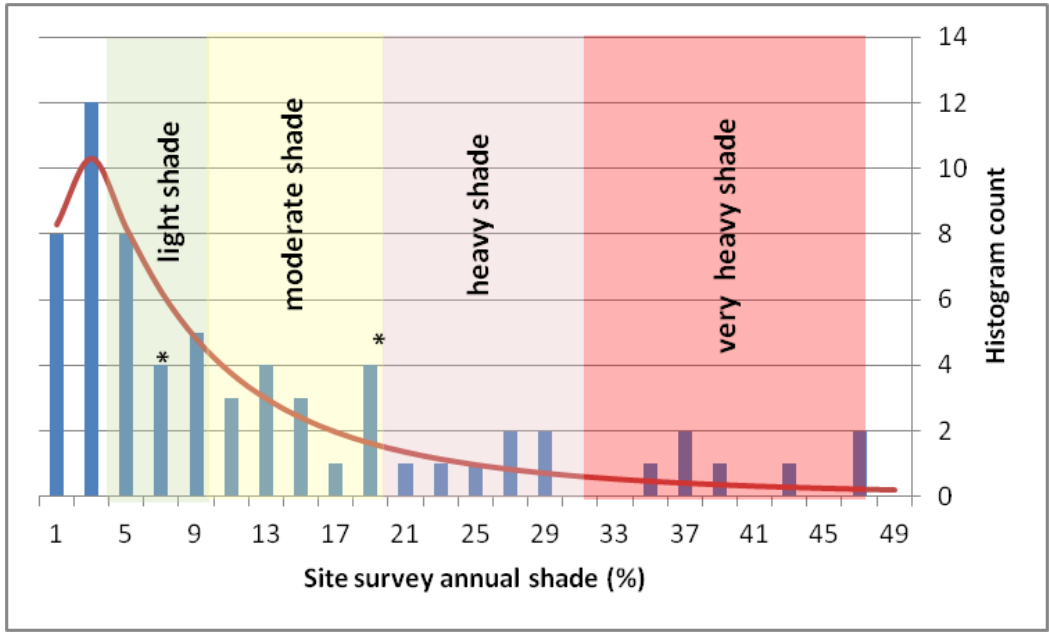
- Tigo: 90% of sales are < 30kW

Business is good and growing:

- Enphase had 13% share of CA installations <10kW in 2010. [8]
- Market is growing >100%/yr

Lots of mismatched PV systems out there:

- Site survey shows 7.6% median shading, with a long tail.



Residential site survey distribution showing 7.6% median annual shading [Solar Works, CA]

[8] Enphase press release dated 1/19/11 based on CSI database for CA installations < 10 kW

Interesting future trends:

- Enphase's efficiency already beats some string inverters (M-215 has $\eta_{CEC} = 96\%$)
- Incremental cost to add DC power optimizers to a system will be 5-10¢/W by 2012.[1]
- Distributed power electronics will account for 1GW, or 5% of inverter capacity by 2013.[2]
- 45% of units will be packaged directly into PV modules by 2015.[2]

1: Tigo energy 2: IMS Research

Additional considerations:

Added benefits to using per-panel devices may include:

- Per-module performance monitoring
- Emergency shut-off or lower voltage for fireman safety
- Ability to add more PV panels at a later date
- Greater freedom in design and layout

Some concerns to keep in mind may include:

- Different devices may not be inter-operable, obsolescence risk may be a concern.
- Insertion loss during unshaded times may offset benefit
- Additional equipment = more points of failure

In conclusion…

- The impact of shade is greater than just the area of shade
- Additional mismatch losses include panel orientation, panel distribution, inverter voltage window, soiling
- Per-module devices can help increase performance, 4-12% or more depending on the system.
- Value-added benefits (safety, monitoring, reduced design constraints) are helping their adoption
- The residential market is growing rapidly. Efficiency increases, cost reductions are improving market acceptance. Panel integration will further reduce price and installation cost. Reliability remains an unknown.

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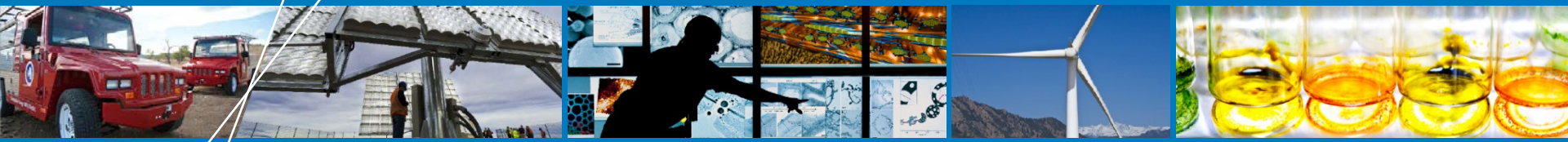
Questions / Comments?



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