Distributed power electronics for PV systems

National Renewable Energy Laboratory’s EPRI PV Technology Seminar

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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
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

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

Inverter Vmp clipping due to high temperature and partial shade

Credit: Solarenergydiysolutions.com
## Example mismatch losses

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

*Not accounting for device efficiency or diode insertion loss

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

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.

[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.
Questions / Comments?

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