Sub-Module Integrated Converters

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- Maximum energy extraction (MPPT control) can be done on multiple levels: String, Module, Cell,…
  - Increased localization greatly benefits energy extraction (compensation for partial shading, cell mismatch, aging, …)
  - Increased localization makes the power electronics more challenging
    • Efficiency, cost, reliability, …

There is tremendous opportunity for high-impact innovation in conversion system architecture and implementation
Considerations in MPPT

• Example system structure (e.g., module-level MPPT)

• Ideal power point tracking curve is only correct for either a single uniformly-illuminated cell or a set of matched cells with identical illumination
System Structure

- Cells WILL NOT stay matched over time (even when binned)
  - Differential shading (clouds, leaves, obstructions), aging effects, damage,…
  - Bypass diodes needed to protect system, reduce energy loss
System Performance

- Even a SINGLE shaded cell can potentially hurt maximum power point extraction by 33% or more (module-level MPPT)
Opportunity for MPPT at Sub-Module Level

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Considerations

- Moving the MPPT to a more local level (downwards in power/voltage) and integrating the conversion is certainly possible
  - Leverage the benefits of CMOS power conversion, which is matched to the low cell voltages
  - Achievable switching frequency (and size of power passives) improves as voltage is reduced

\[ R_{on}C_{g} \propto V_{sw} \]

CMOS scaling improves device performance
At low voltages (commensurate with cells)

Optimum CMOS Buck Converter Switching Frequency

\[ f_{s_{-opt}} = \frac{P_{loss}^{2}(\text{min})}{4I_{out}^{2}V_{in}^{2}R_{0}C_{0}} \]

Considerations

• Integrated low-power MPPT is feasible and has been demonstrated in some applications (e.g., TPV…)

• Many potential benefits
  – Robustness to shading, mismatch, ageing, cell damage,…
  – Flexibility of placement, fault tolerance, ease of installation

• Many challenges, unknowns
  – Control and coordination: Four horses or a million mice?
  – Packaging and manufacturing
  – System cost implications
  – Control dynamics
  – Efficiency
    • High efficiency is easy to achieve at large scales, but becomes more challenging at small scales (where localized MPPT benefits)