



Sub-Module Integrated Converters

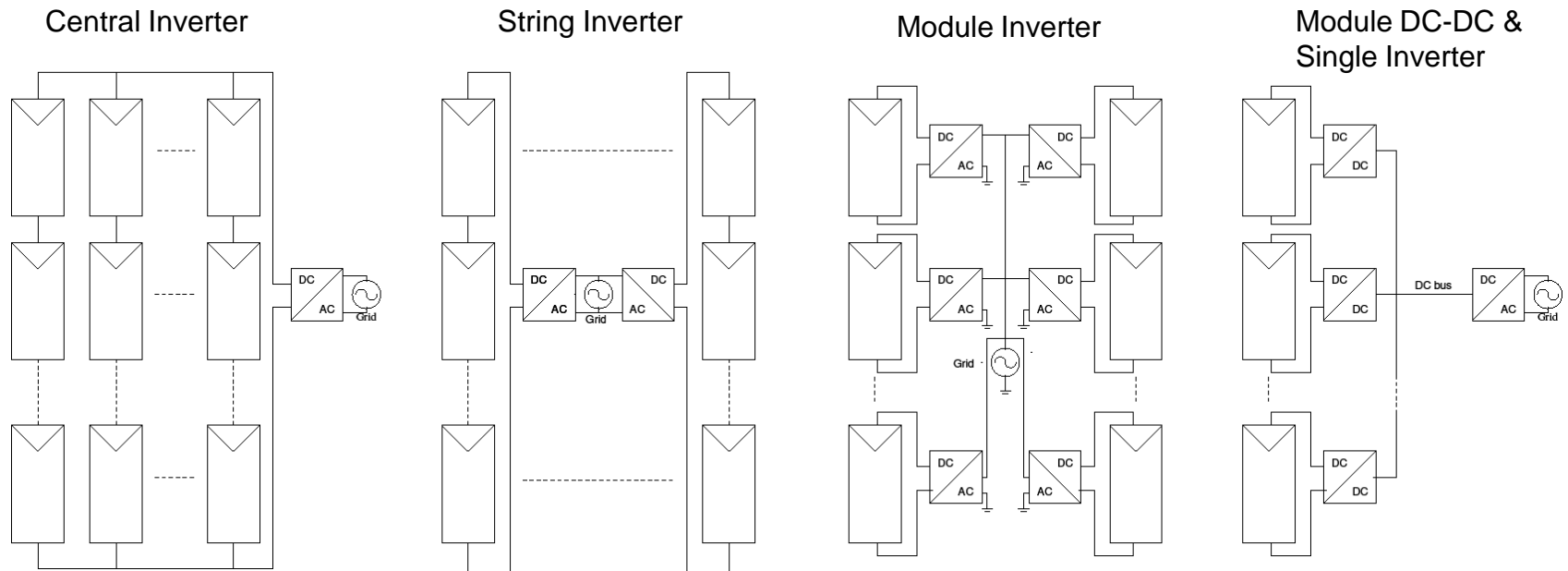
David Perreault, MIT

DOE PV Workshop

February 2011

MOSIS
V01C-AE
1016

Photovoltaic Systems

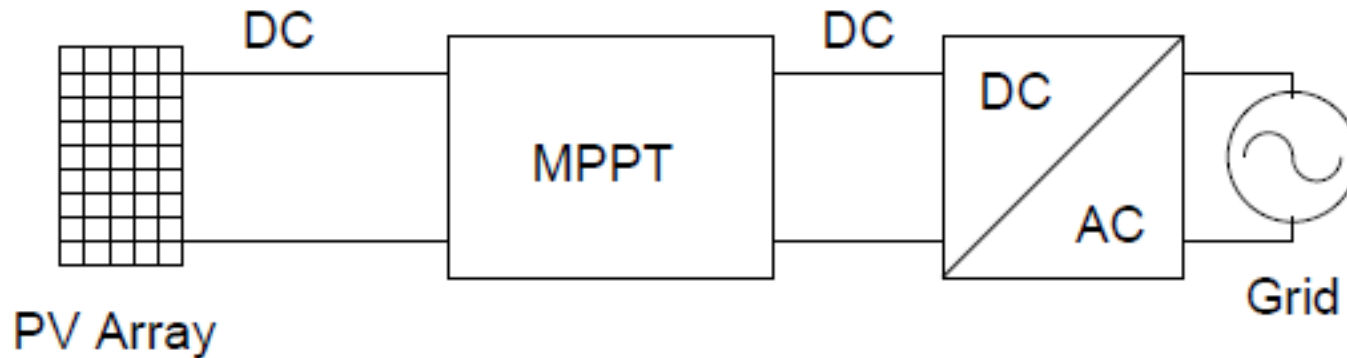


- Maximum energy extraction (MPPT control) can be done on multiple levels: String, Module, Cell, ...
 - Increased localization greatly benefits energy extraction (compensation for partial shading, cell mismatch, aging, ...)
 - Increased localization makes the power electronics more challenging
 - Efficiency,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

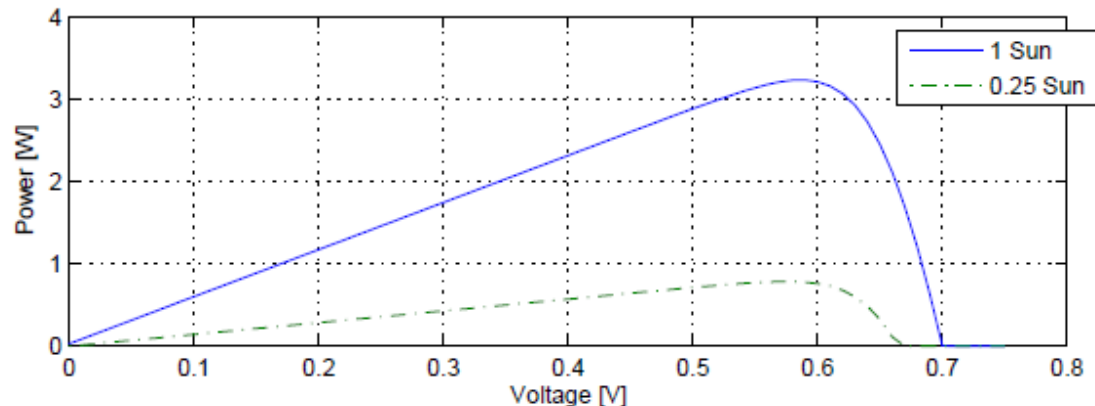
There is tremendous opportunity for high-impact innovation in conversion system architecture and implementation

Considerations in MPPT

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

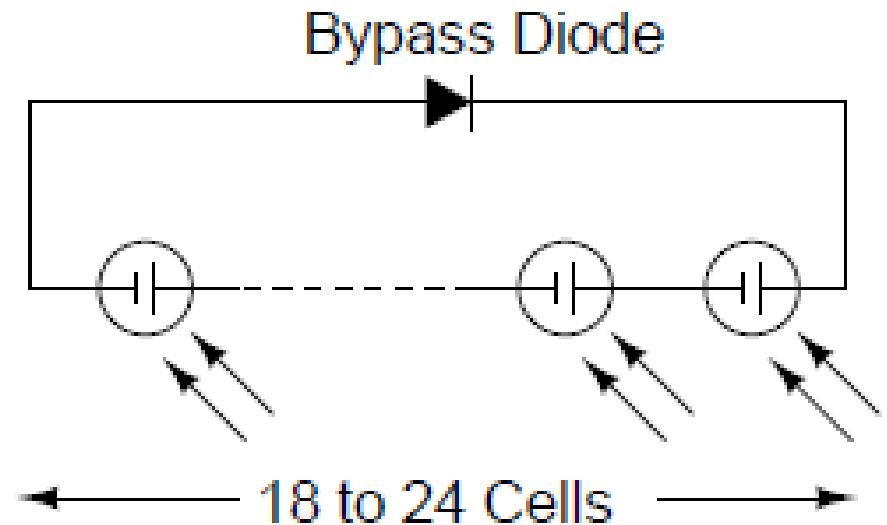
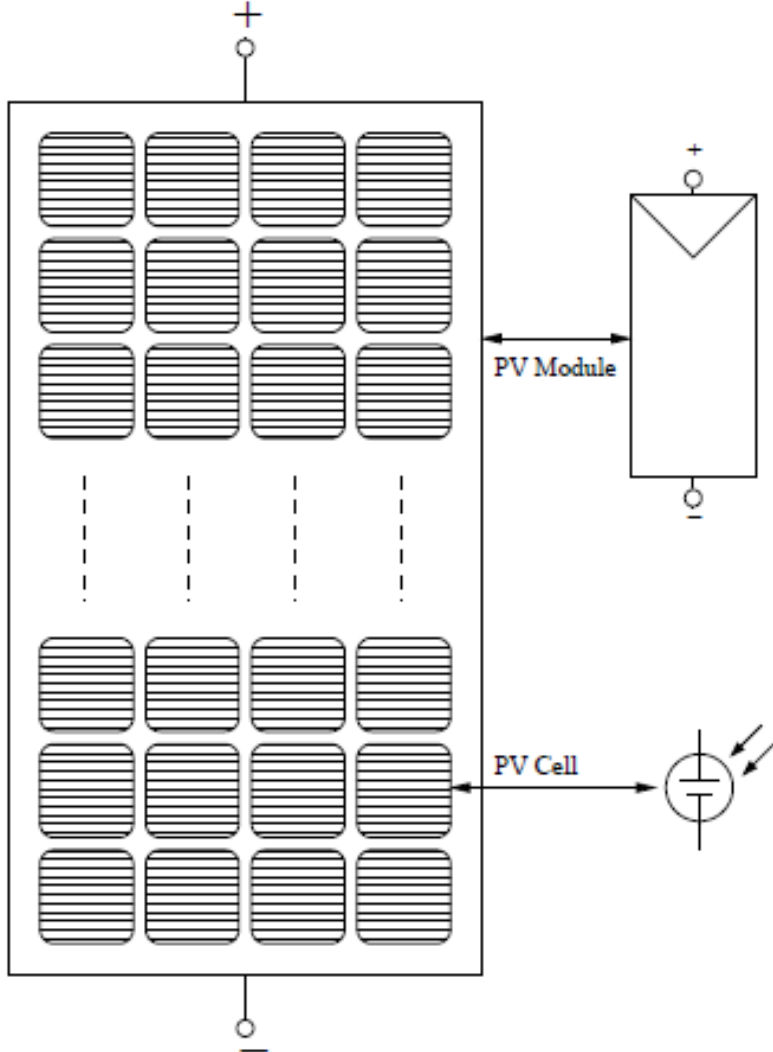


- Ideal power point tracking curve is only correct for either a single uniformly-illuminated cell or a set of *matched* cells with *identical illumination*



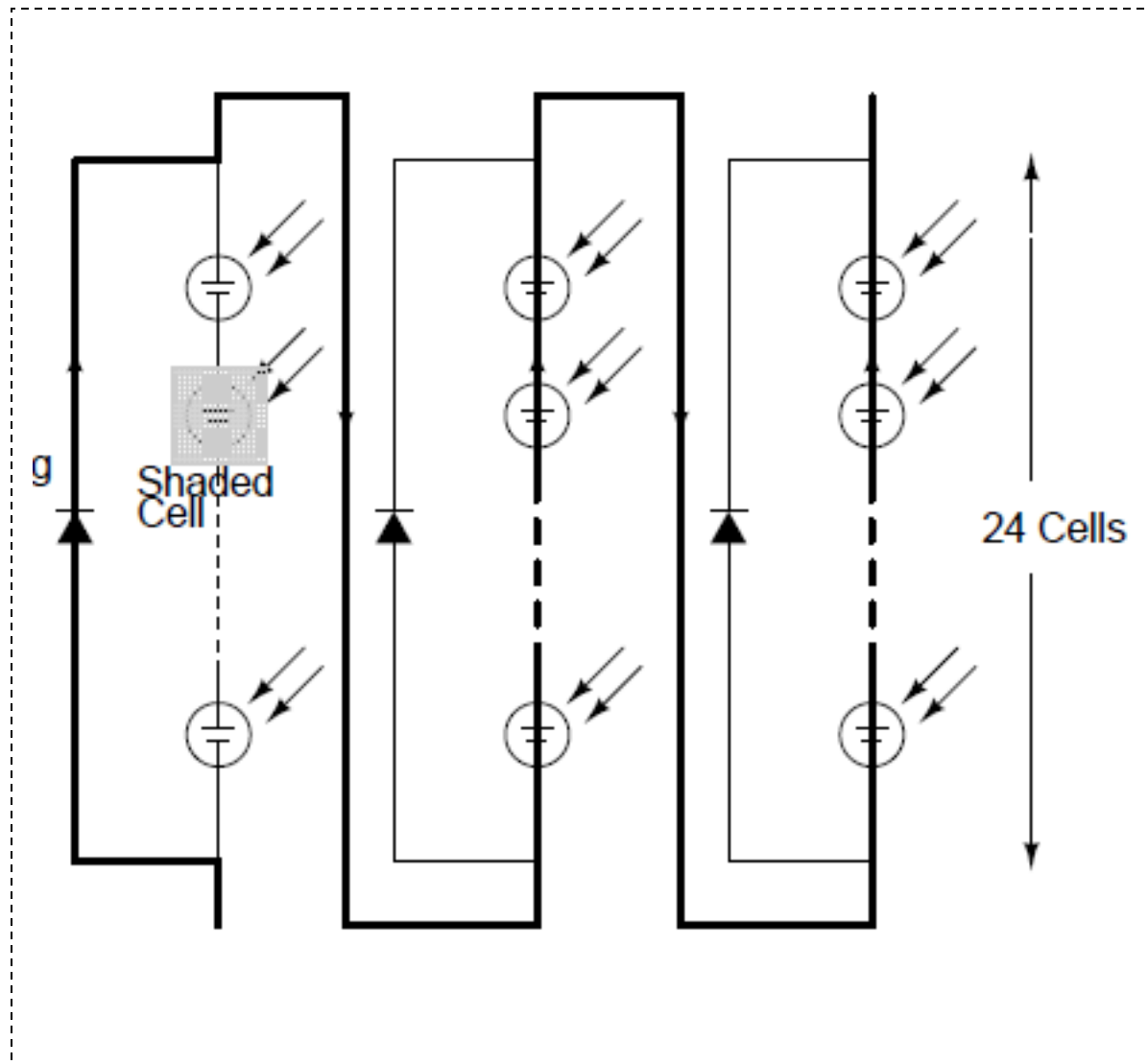
System Structure

- 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

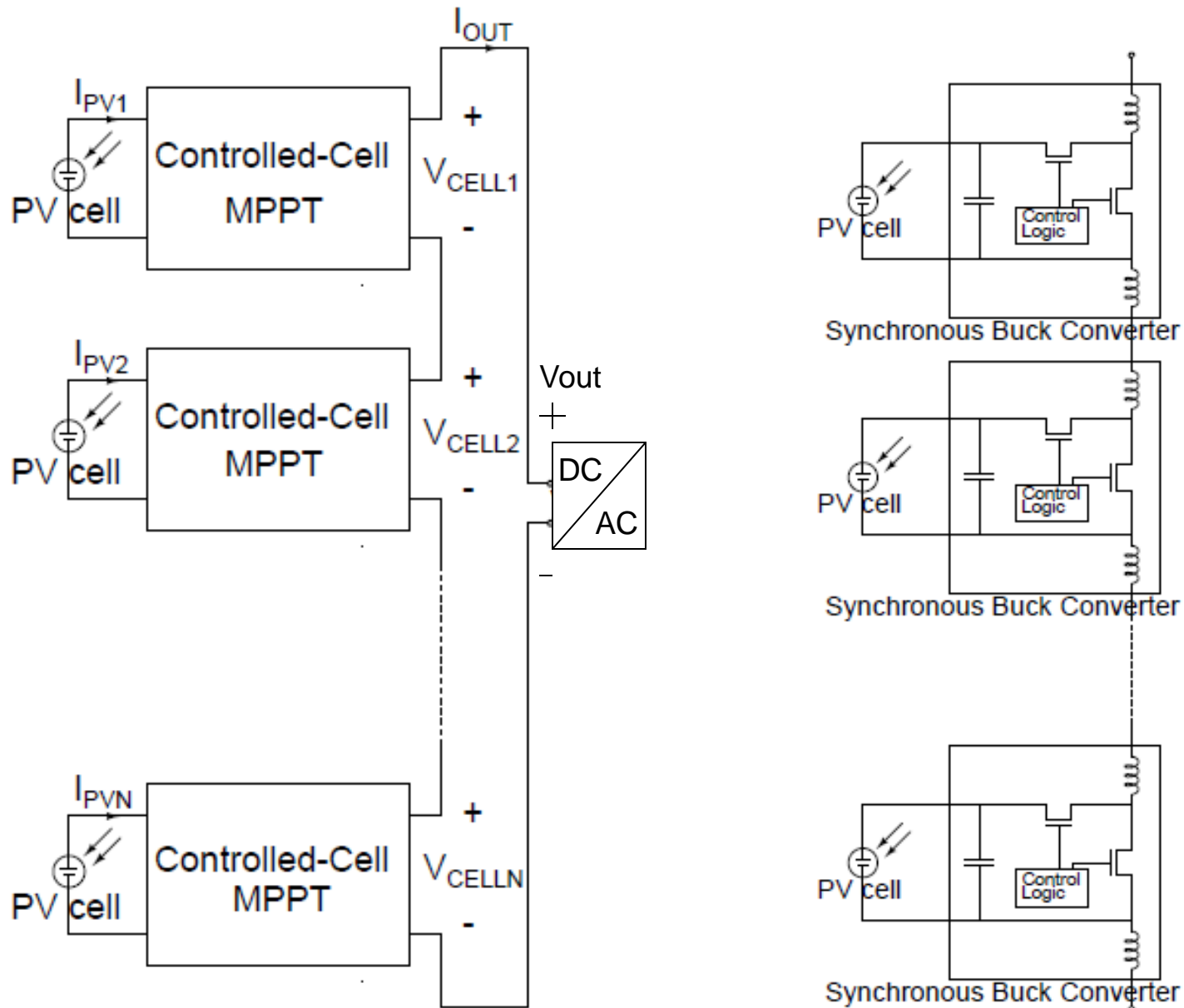


System Performance

- Even a SINGLE shaded cell can potentially hurt maximum power point extraction by 33% or more (module-level MPPT)

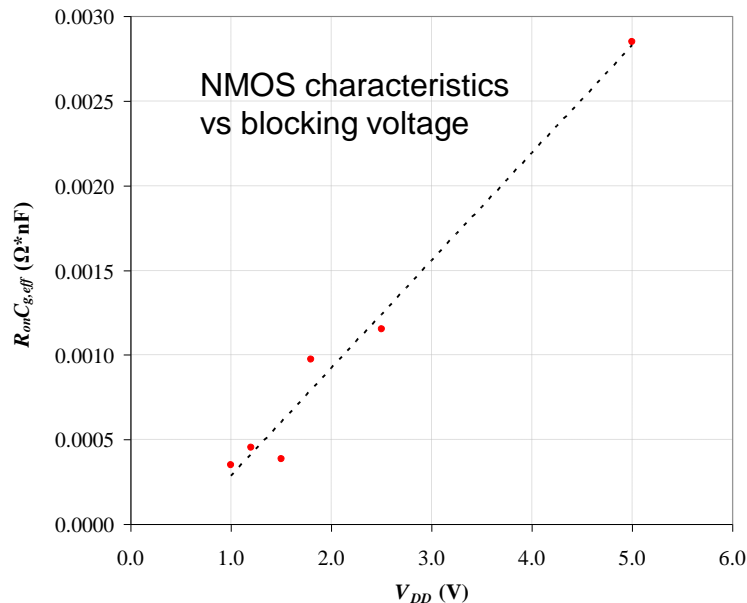


Opportunity for MPPT at Sub-Module Level



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

$$f_{s_opt} = \frac{P_{loss(min)}^2}{4I_{OUT}^2 V_{IN}^2 R_0 C_0}$$

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)

Die Photo, Integrated MPPT & power stage, Pilawa, Li, & Perreault MIT, 2010 (4x4 mm)

