Effects of Degradation on Solar Photovoltaic Systems

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Motivation

• “Go Green”
  – Reduce carbon emissions
  – Utilize renewable energy

• Lower electricity cost

• Tax Benefits
Solar PV Considerations

**Customer Perspective**

- Installation Costs
  - Equipment
  - Labor
- Warranty (25 years)
- Maintenance
  - Upkeep
  - Part replacement
- Payback time

**Engineering Perspective**

- Efficiency
- Reliability
- Fault-tolerance

Maximize System W/$
If PV was a Superhero...

Weakness = Mismatch

Enemies

1. Dust accumulation
2. Partial shading
3. Degradation

[http://www.applied-solar.info]
PV Mismatch

(a) Current vs. Voltage

- PV 1: 1000 W/m²
- PV 2: 500 W/m²

(b) Power vs. Voltage
PV Mismatch

Each Panel

Series String
(with bypass diode)
PV Cell Binning

Wde HiPerforma™
245 W - 240 W

Vd
275 W - 280 W

Vd SuperPoly
285 W - 290 W

[Images: http://am.suntech-power.com/]
PV Cell Binning

- Laborious
- Adds Cost

Huge effort to reduce mismatch
PV Degradation Model

- Mean, $\mu$
  - decreases over time
  - 1 to 0.5% per year (Si)
- Standard Deviation, $\sigma$
  - increases over time
  - More studies required

[http://www.poweredbysearch.com/canadian-seo]

[3] Vazquez and Stolle
Variation Effects on String Power
Variation Effects on String Power

\[ CV = \frac{\sigma}{\mu} \]
Overcoming Mismatch

**Cascaded Architecture**

**Differential Architecture**

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**Overcoming Mismatch**

**Cascaded Architecture**
- Panel level control
- Converters
  - Process 100% power
  - Rated for panel
- Higher Cost

**Differential Architecture**
- Panel level control
- Converters
  - Process fraction of power
  - Rated less than panel
- Lower Cost

Increased power at Lower cost ➔ Increased W/$
Summary

• PV System Design Goal:
  Maximize watt per dollar (W/$)
• PV mismatch greatly reduces output power
• Cell binning reduces mismatch within panel
• Degradation over time
  – Mean power decreases
  – Standard deviation increases
• Differential Power processing
  – Overcome string variation losses
  – Higher efficiency, lower cost than cascaded
Selected References


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Questions?