Introduction to Photovoltaic Systems

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TCIPG Reading Group

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(Flexible) Agenda

I. Photovoltaic (PV) Basics

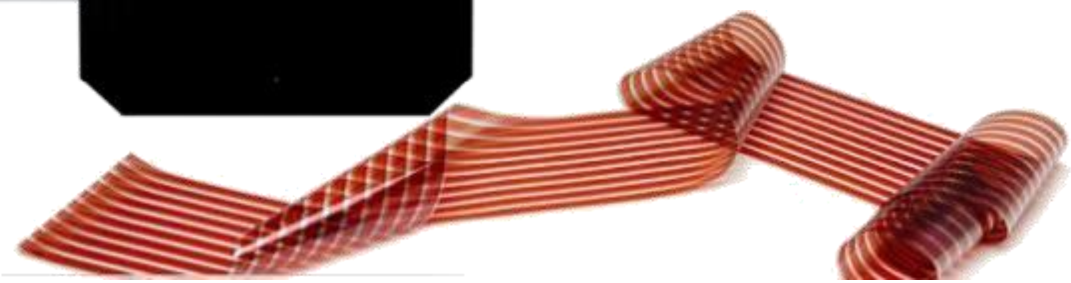
II. PV Power Systems
   1. Architecture
   2. Control

III. Summary

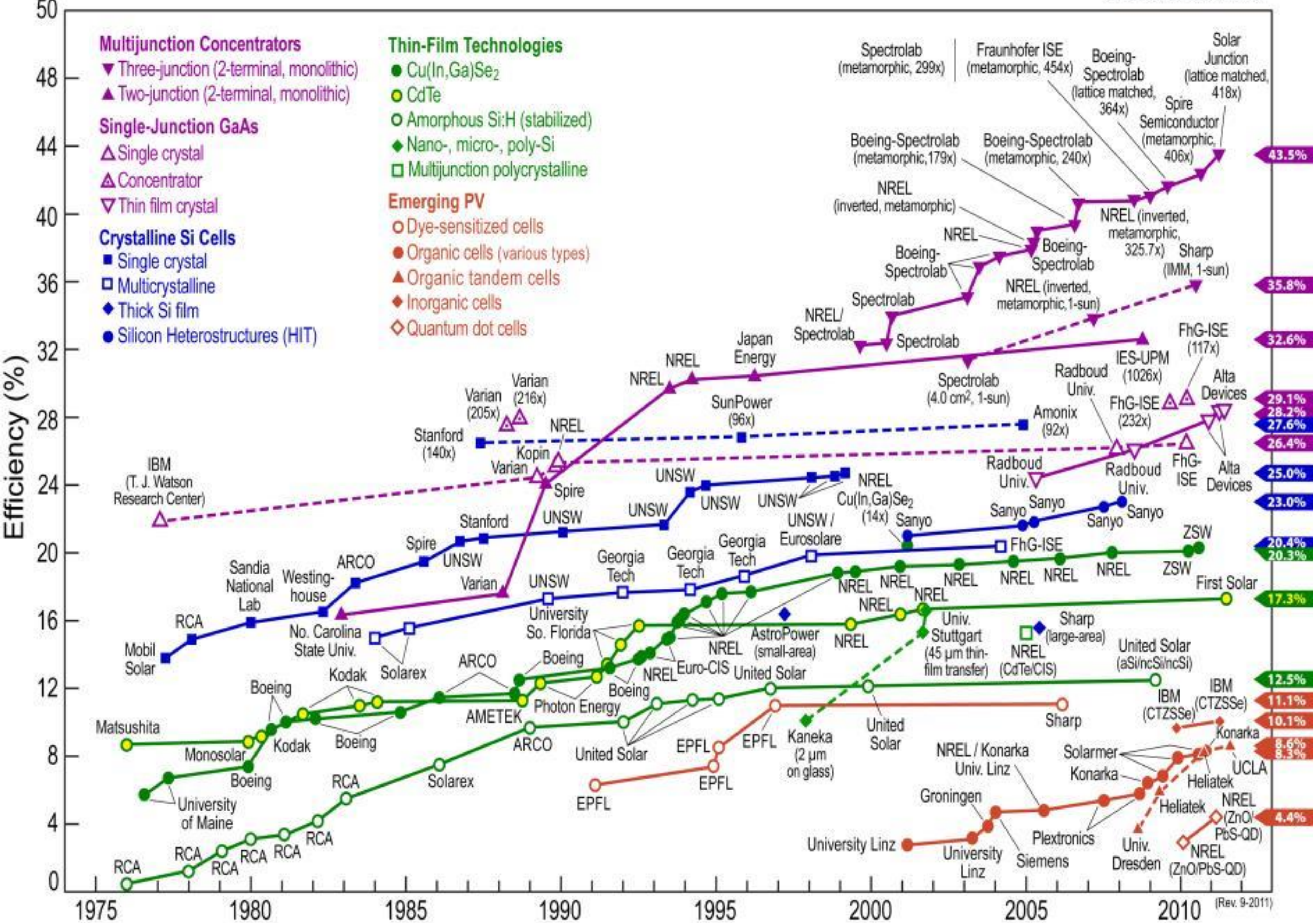
I. PV Basics

Photovoltaic (PV) Materials

- Crystalline Si
  - Monocrystalline
  - Polycrystalline
- Thin-film
  - Copper indium gallium selenide (CIGS)
  - Cadmium telluride (CdTe)
  - Amorphous silicon (A-Si)
- Multi-junction
  - Double-junction
  - Triple-junction



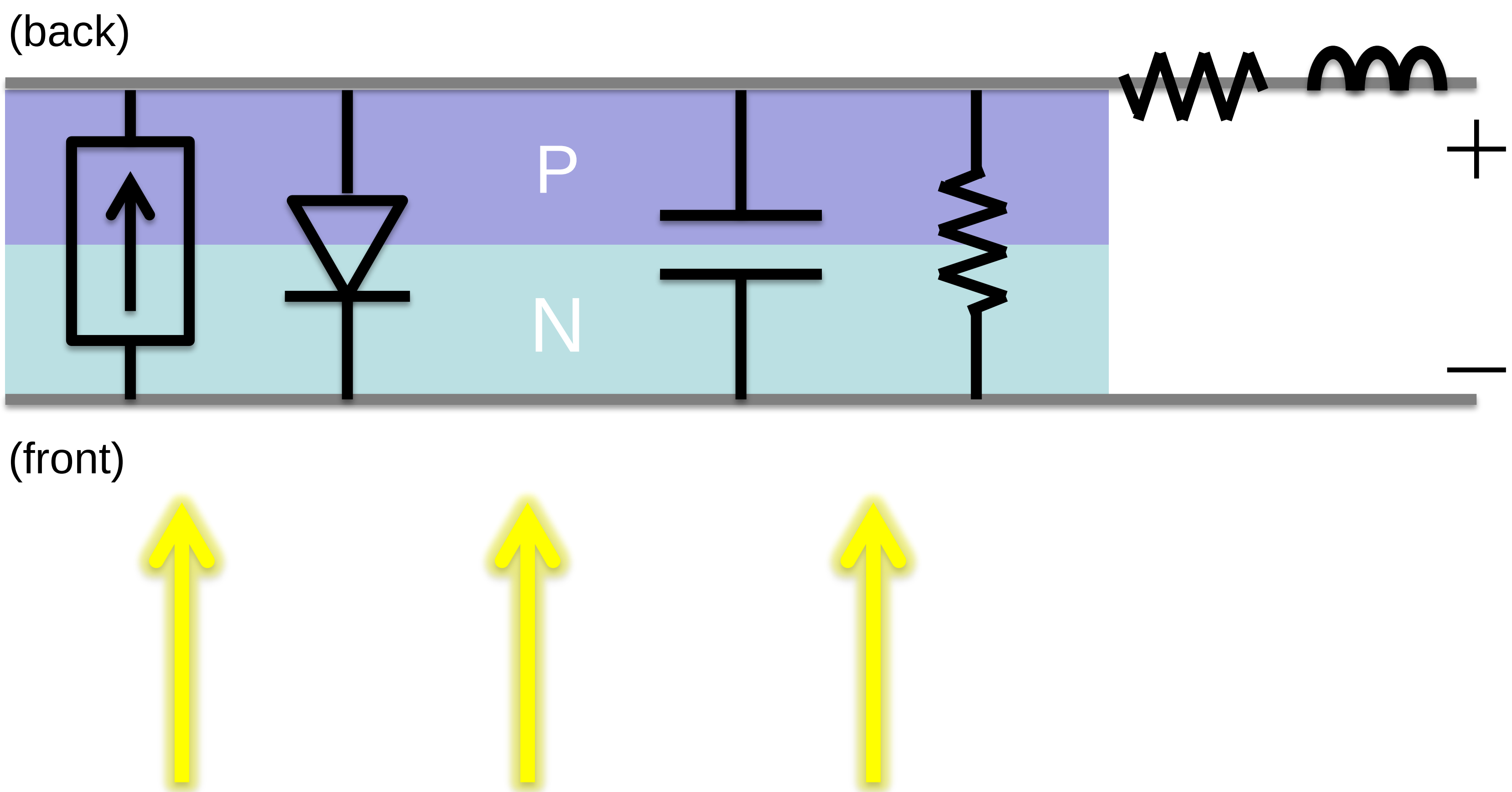
Best Research-Cell Efficiencies



Question

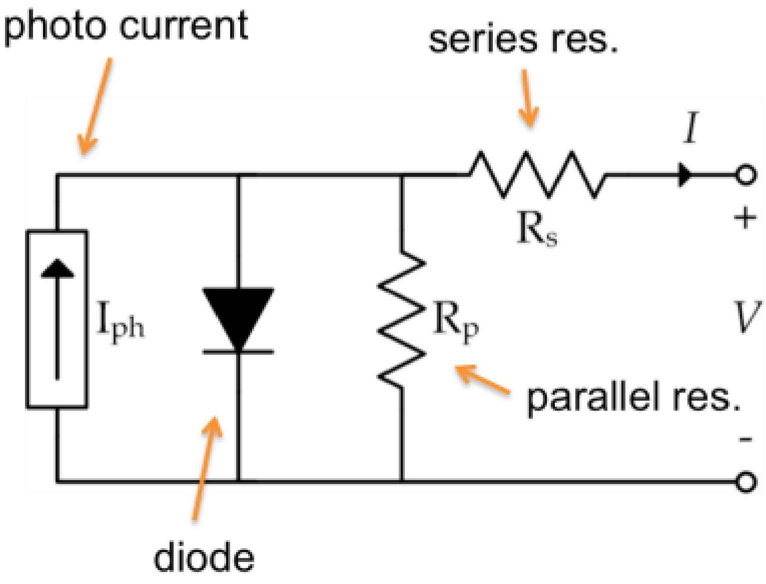
- If PVs can have such a high efficiency, why do we still primarily use the lower-efficiency Si PV cells?

Photovoltaic Cell Basics

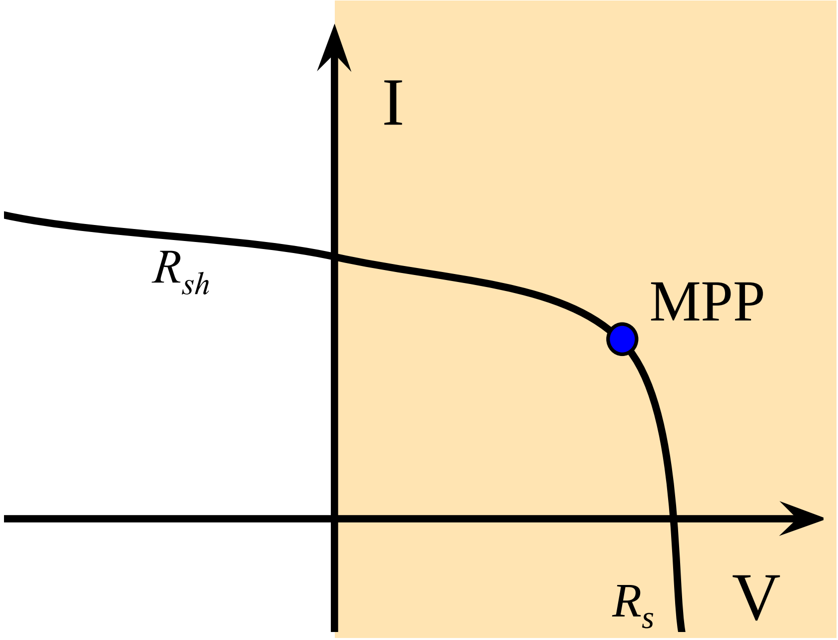


Single-Diode PV Model

Single-Diode DC Model

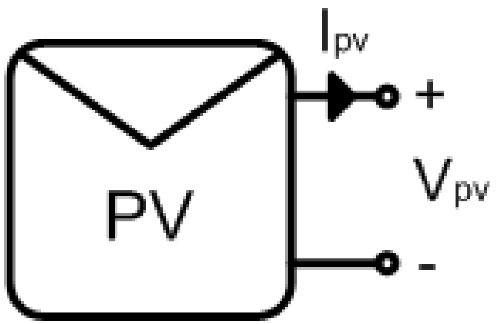


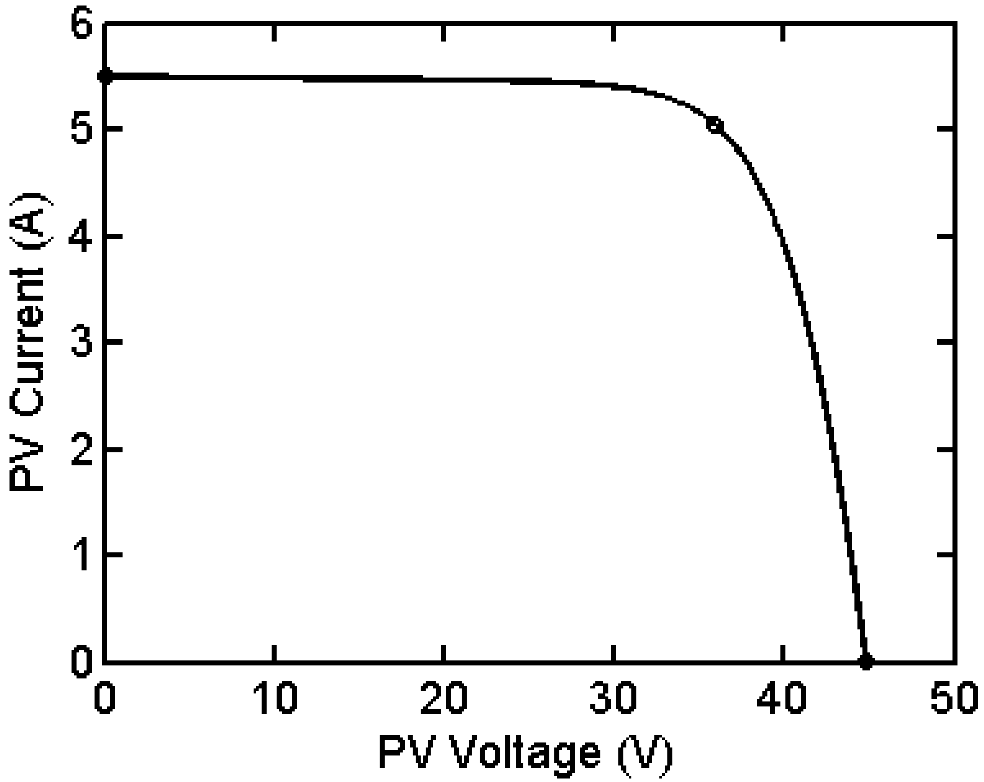
I-V Characteristics



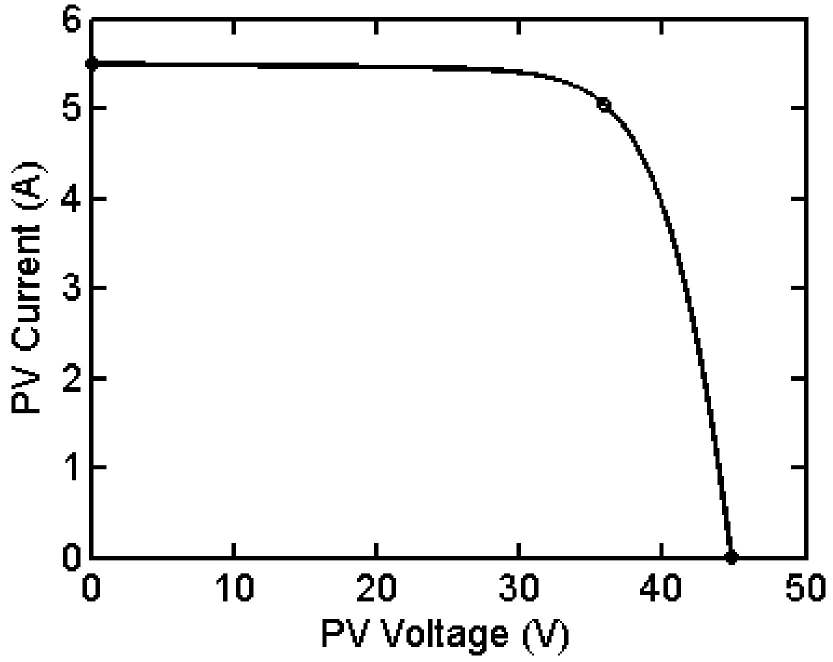
Good for **forward dc** characteristics.

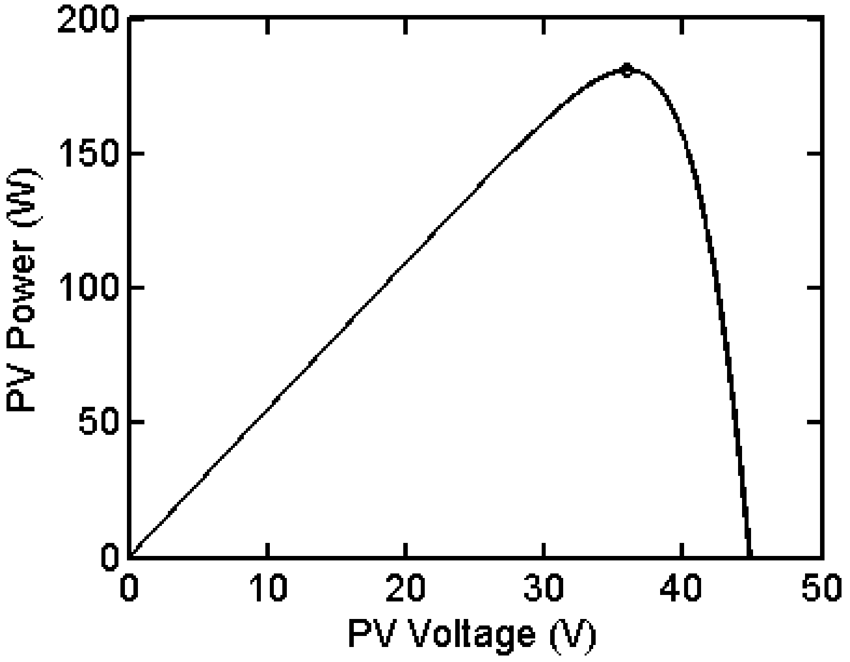
PV I-V Characteristics





I-V and P-V Curves





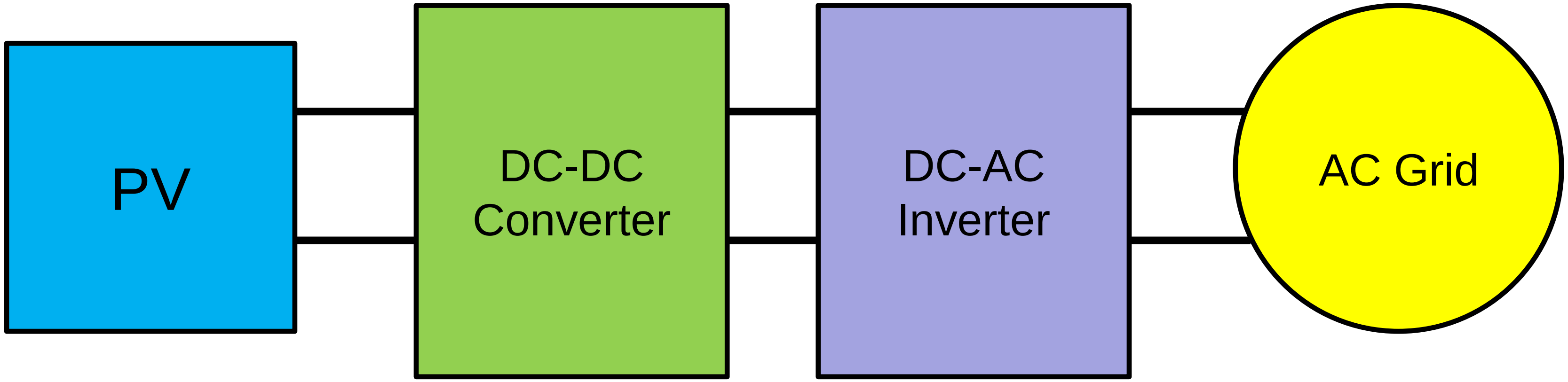
P = I V

II. PV Power Systems

Residential PV System

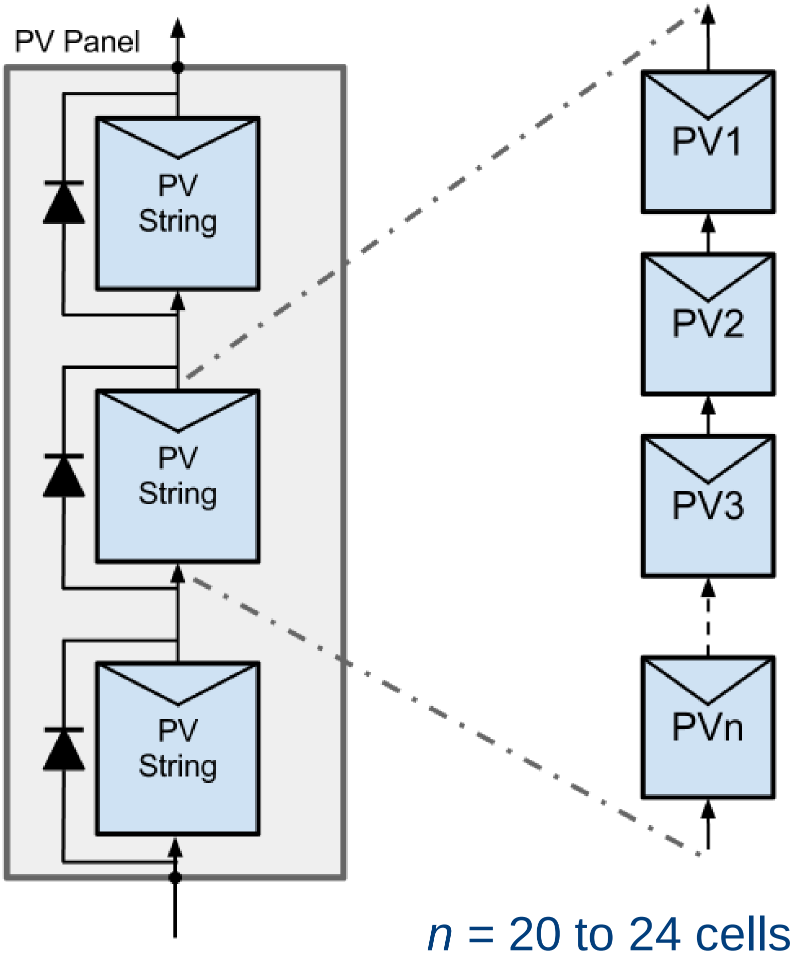
1. PV Architectures

Grid-Connected PV Power System



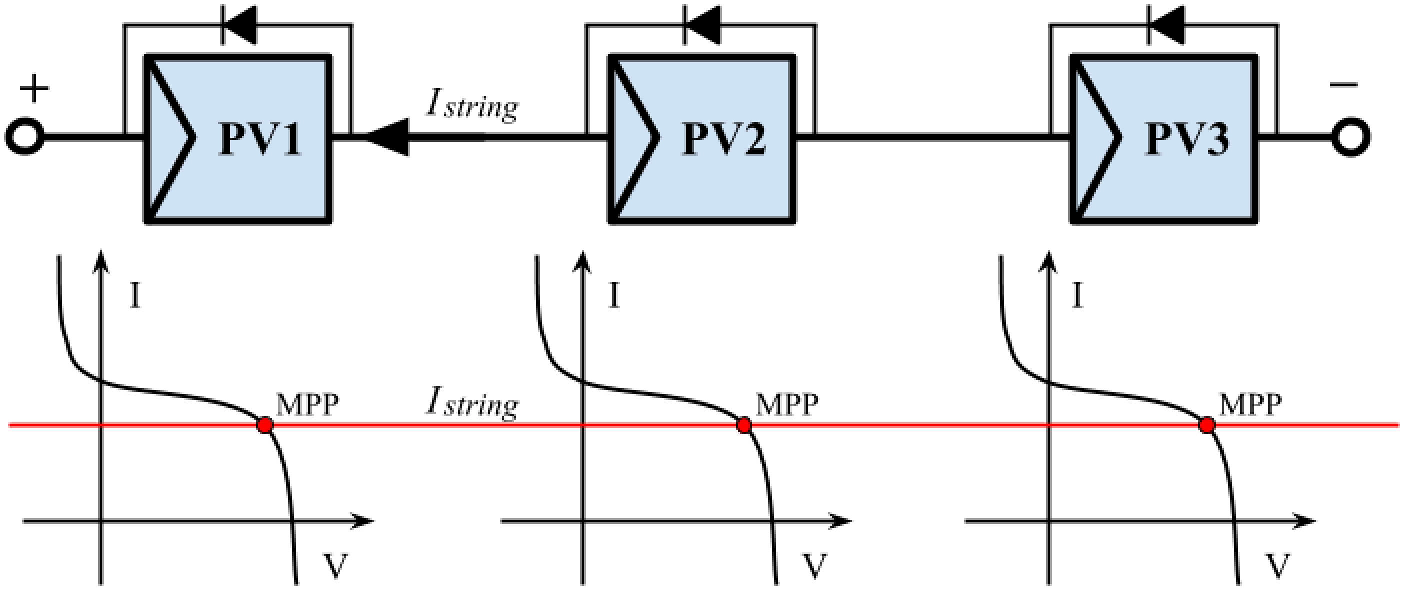
PV Panels Consist of Substrings

[Image Source: GreenSourceGS.com]

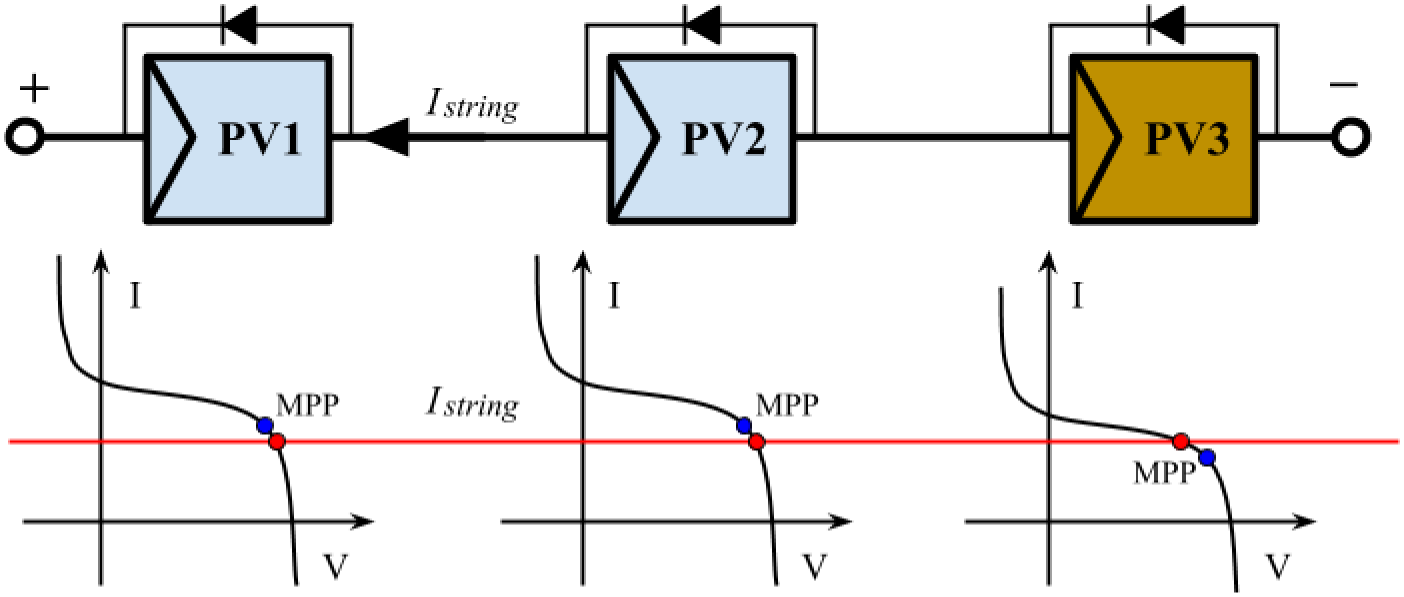


n = 20 to 24 cells

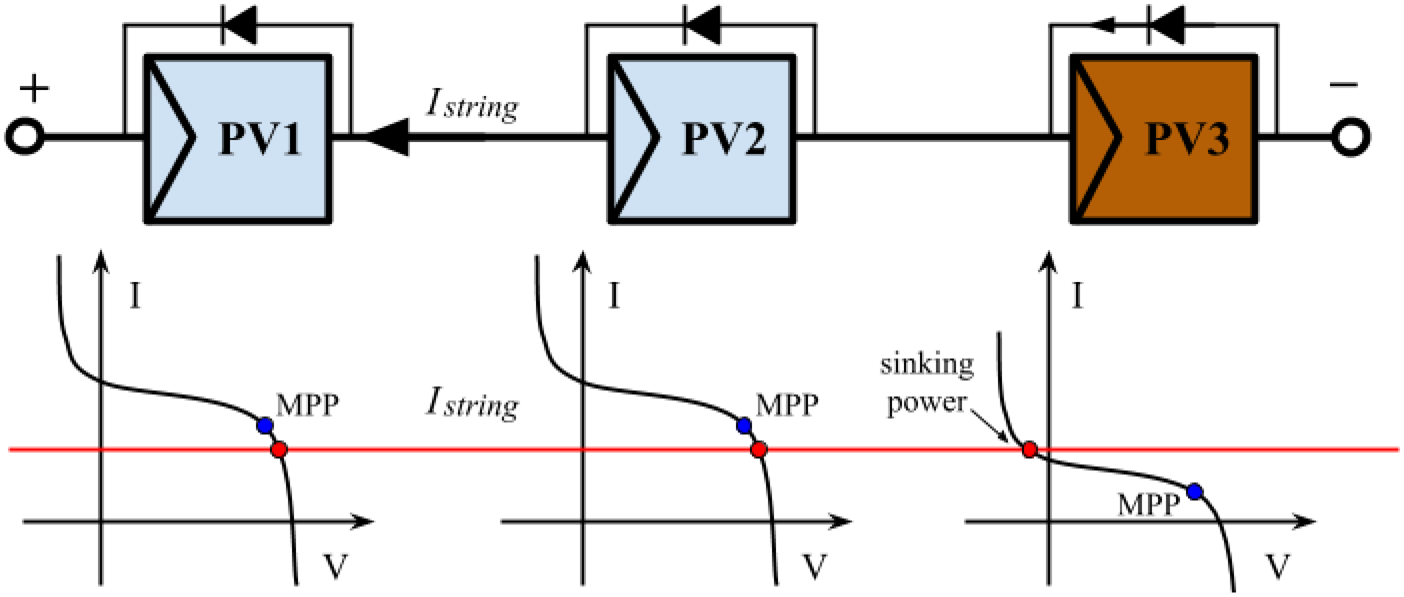
PVs in Series – Ideal



PVs in Series – Degraded

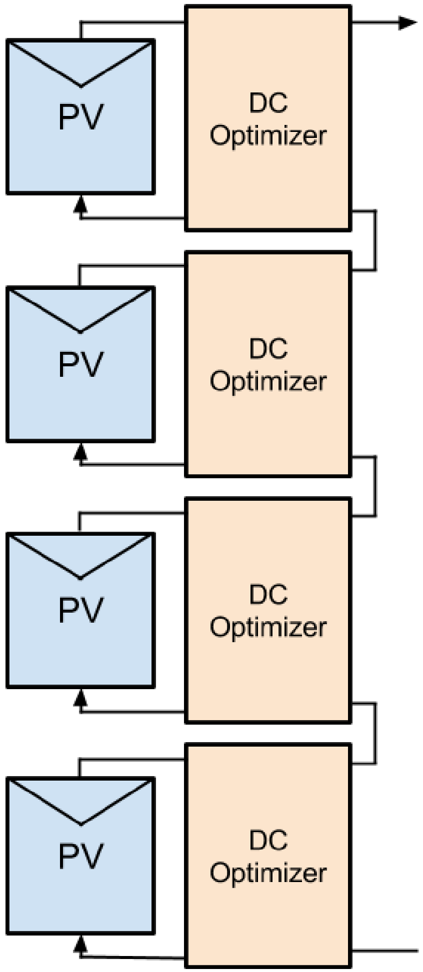


PVs in Series – Heavily Degraded



Mismatch causes power loss in series strings

Overcoming Mismatch – DC Optimizer



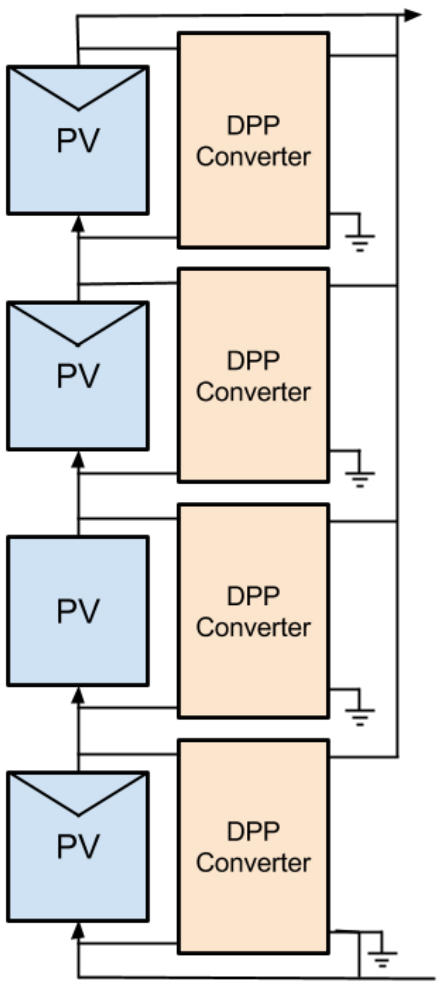
- Panel-level
- Independent MPP control of each panel
- Processes 100% power
- Power rated for panel
- Maximum output is proportional to efficiency

[1] Walker and Sernia, IEEE Trans. Power Electron., 2004.

[2] Deline and MacAlpine, Energy Conv. Congr. Expo., 2013.

[3] Pilawa-Podgurski and Perreault, IEEE Trans. Power Electron., 2013.

Overcoming Mismatch – DPP



- Subpanel-level
- Independent MPP control of each string
- Lower power processed
- Lower power rating
- Higher output than dc optimizers

[4] Shenoy, et al., IEEE Trans. Power Electron., 2012.

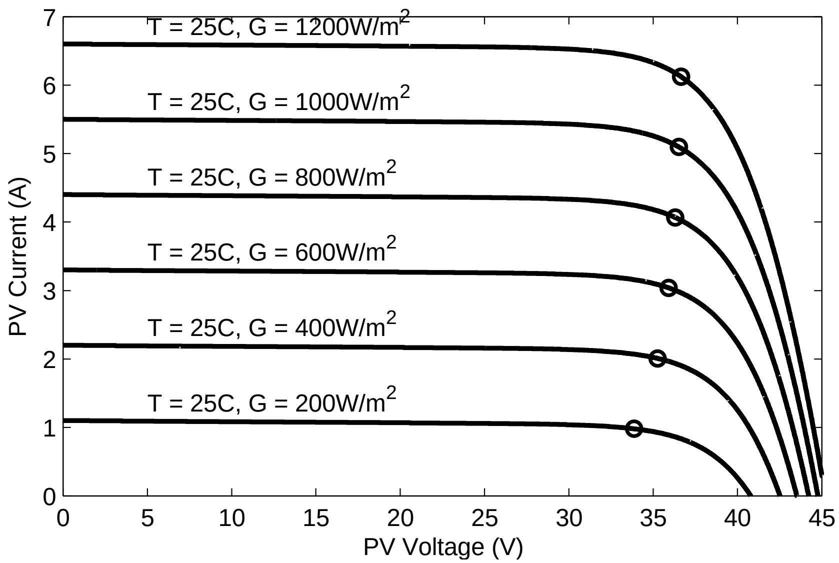
[5] Stauth, et al., IEEE Trans. Power Electron., 2013.

[6] Olalla, et al., IEEE Trans. Power Electron., 2013.

2. PV Control

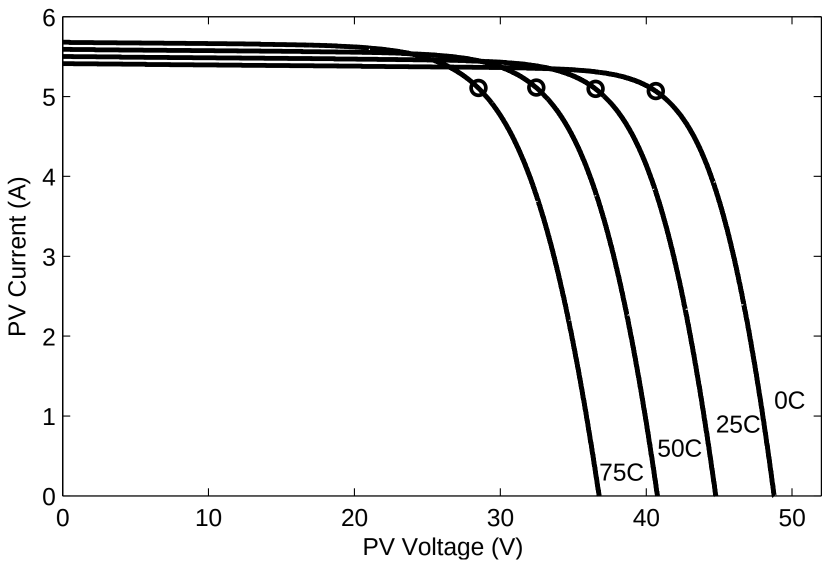
I-V Curve Under Varying Conditions

Irradiance (G) Variations



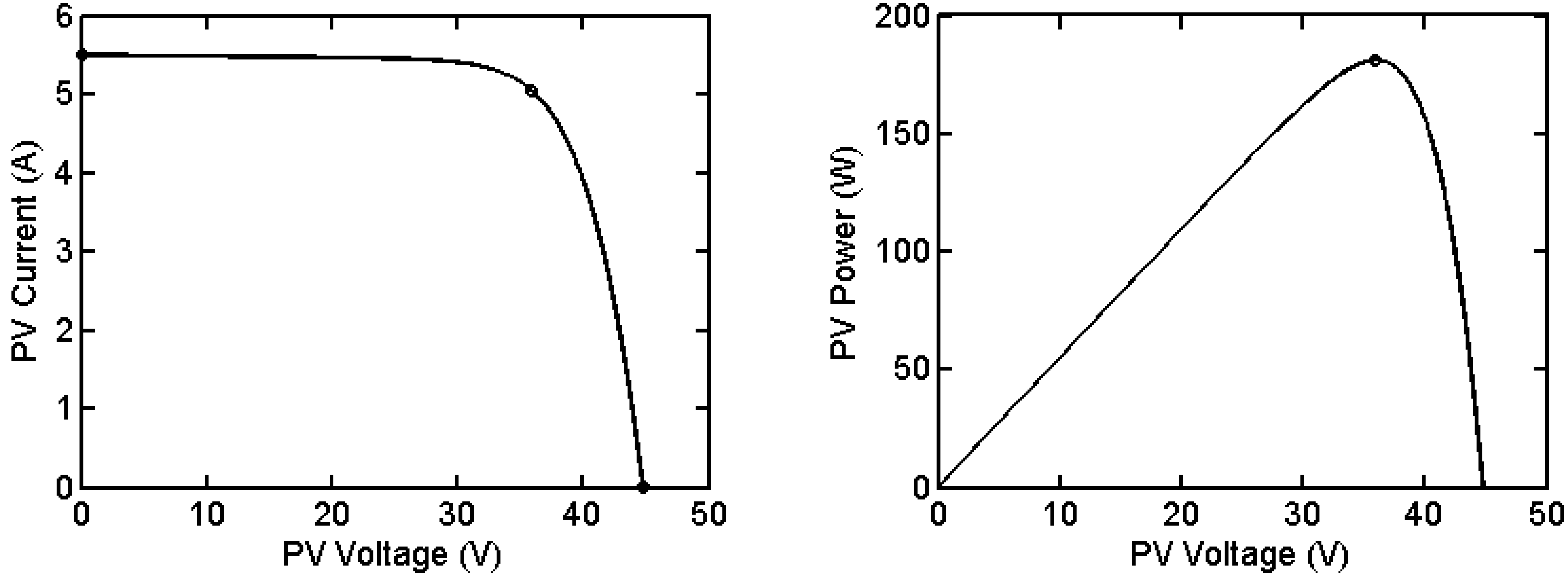
Irradiance directly proportional to short-circuit current

Temperature (T) Variation



Temperature inversely proportional to open-circuit voltage

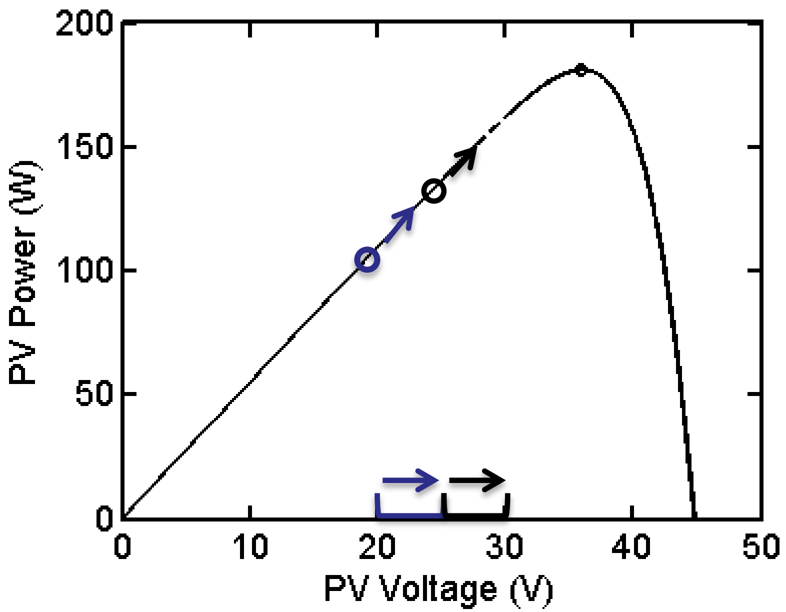
Maximum Power Point Tracking



Given that you can only read the instantaneous I and V, how can we find the MPP?

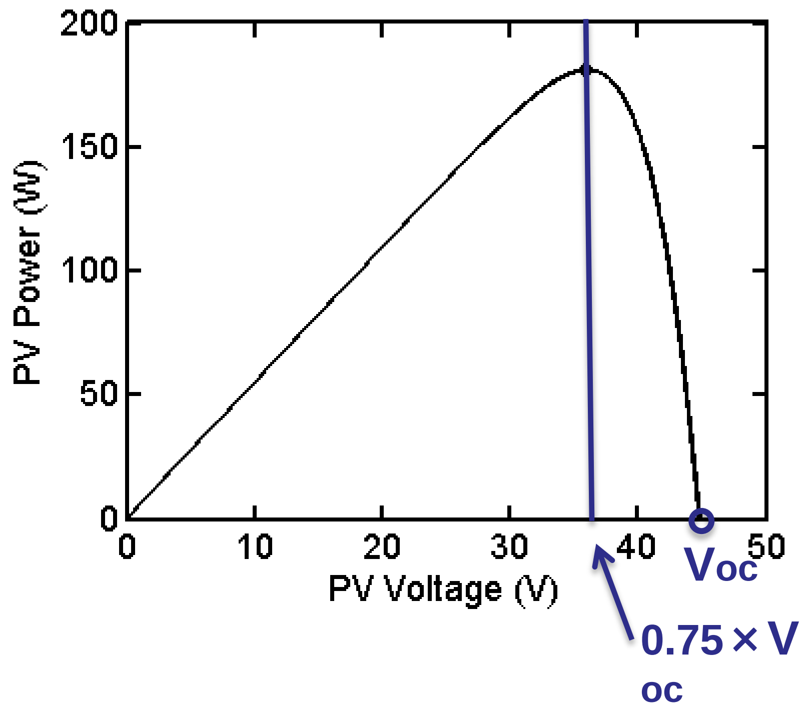
Maximum Power Point (MPP) Tracking

- Perturb and Observe
  - Measure I and V
  - Calculate P
  - Compare to last measurement
  - Incremental steps
  - Climbs toward MPP

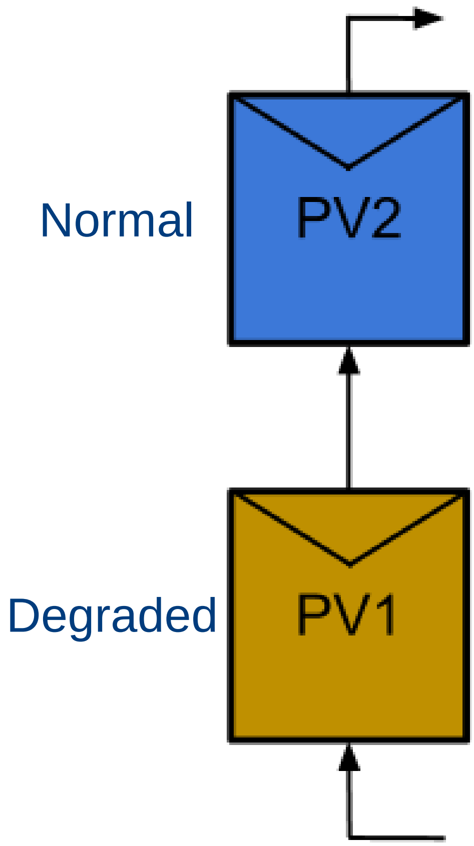


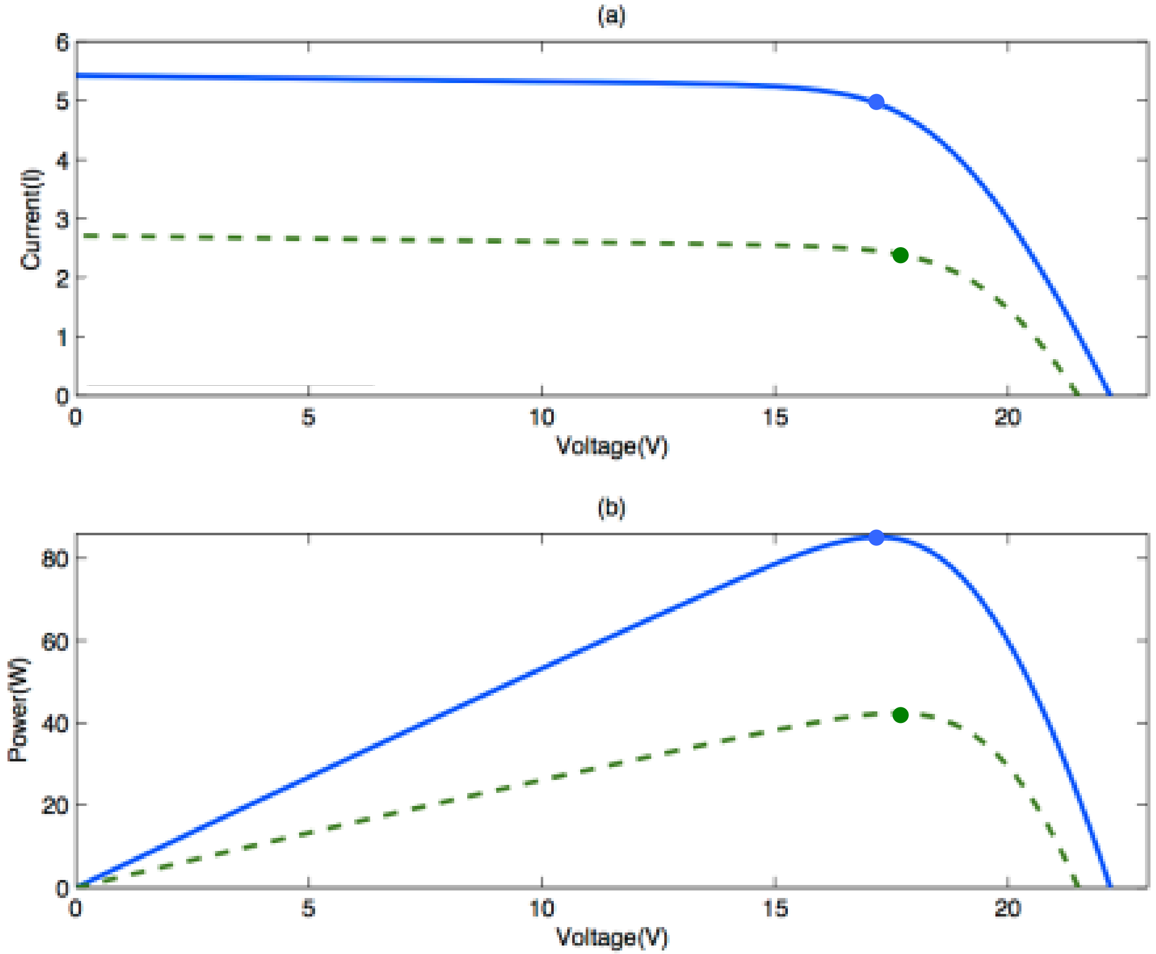
Maximum Power Point (MPP) Tracking

- Fractional Open-Circuit Voltage (V_{oc})
  - Measure V_{oc}
  - Set V to fraction V_{oc}
  - Usually 70-80%

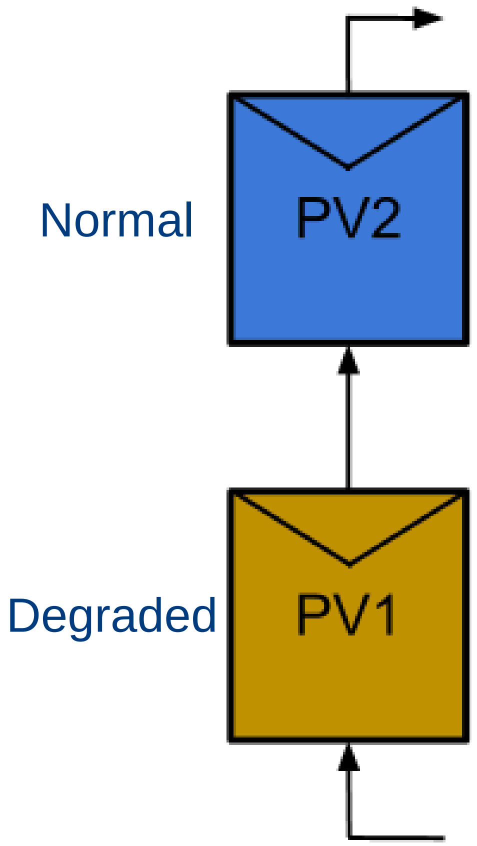


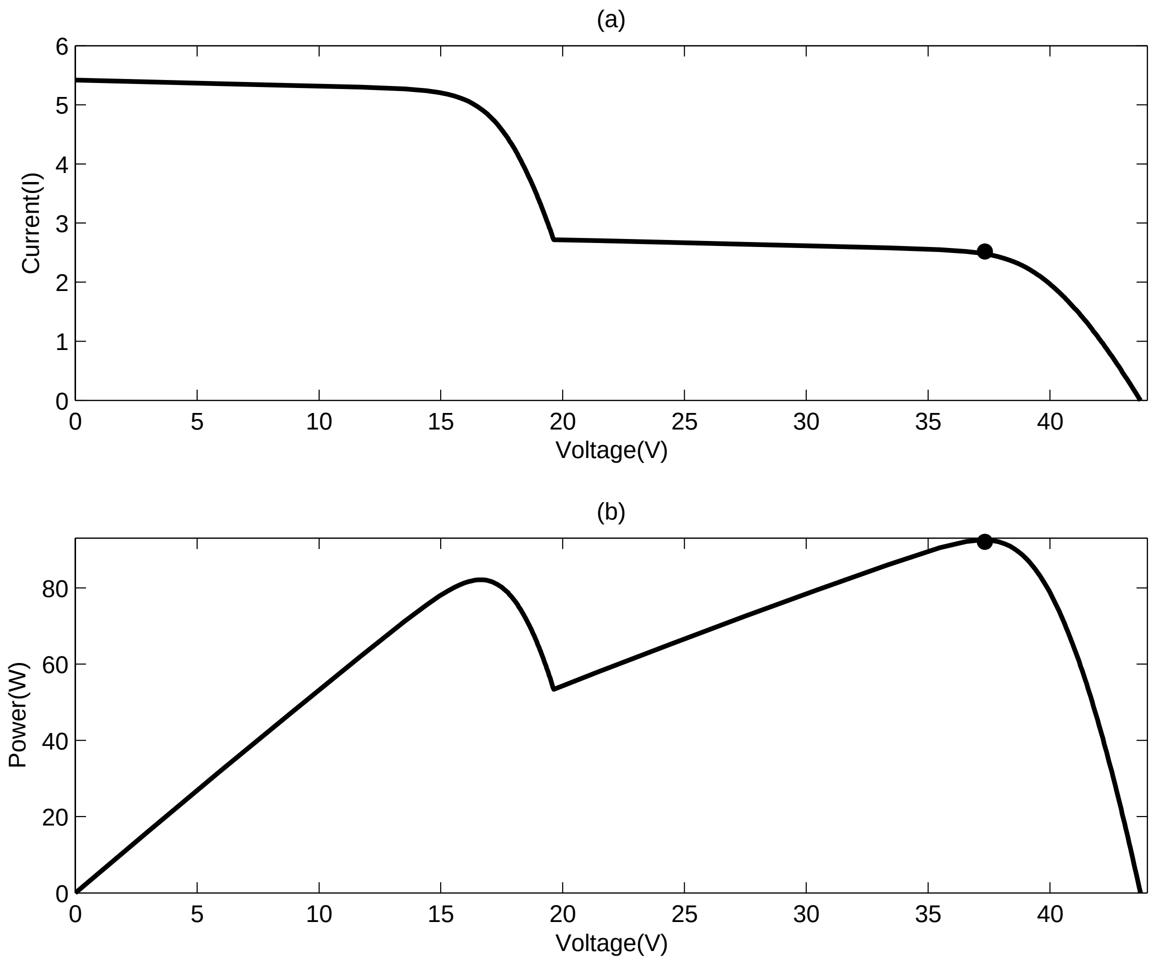
Another Control Challenge: PV Mismatch





How do we consistently find the MPP?





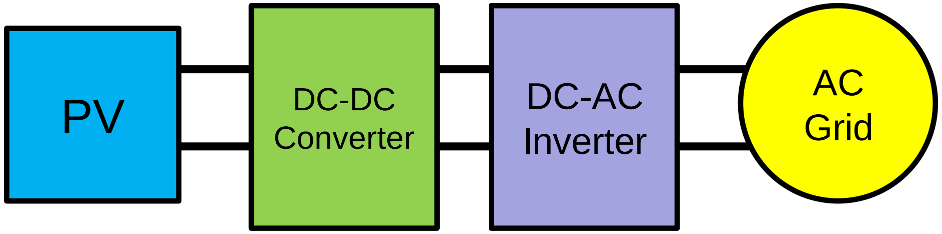
Many algorithms cannot find global MPP.

III. Summary

Summary

I. Photovoltaic (PV) Basics
   - Various PV materials, but Si used mainly because of low cost
   - PVs need to be operated at their MPP

II. PV Power Systems



1. Architecture
   - Dc optimizers
   - Differential power processing converters promising
2. Control (MPP Tracking)
   - Perturb and observe, fractional open-circuit voltage
   - Challenges with multiple power peaks from partial shading

Questions?

Photo by Helen Hwang