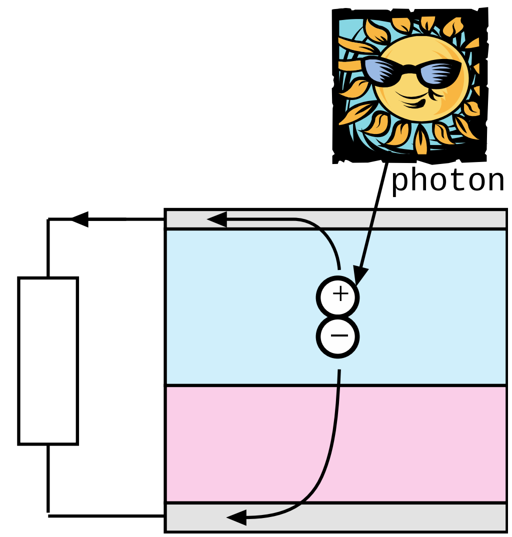
Development of Electrical Model of the Photovoltaic Cell, slide 1

Photogeneration

Semiconductor material absorbs photons and converts into hole-electron pairs if

Photon energy $h\nu > E_{gap}$ (*)

- Energy in excess of E_{gap} is converted to heat
- Photo-generated current I_0 is proportional to number of absorbed photons satisfying (*)

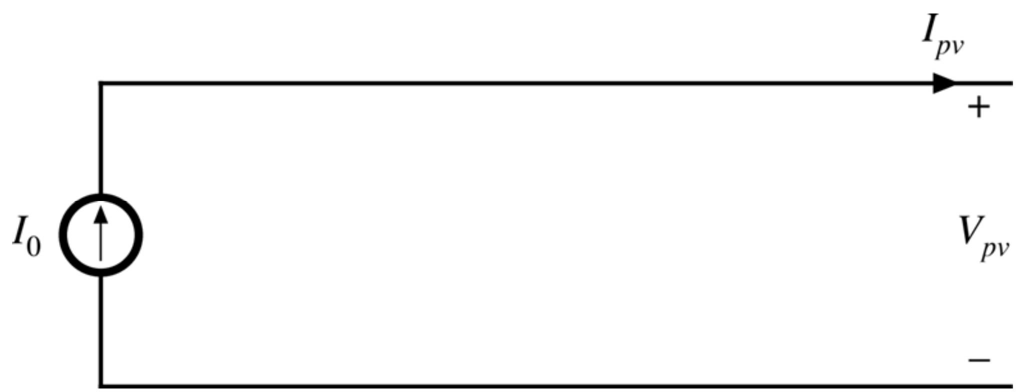


Charge separation

Electric field created by diode structure separates holes and electrons

Open circuit voltage V_{oc} depends on diode characteristic, $V_{oc} < E_{gap}/q$

Development of Electrical Model of the Photovoltaic Cell, slide 2



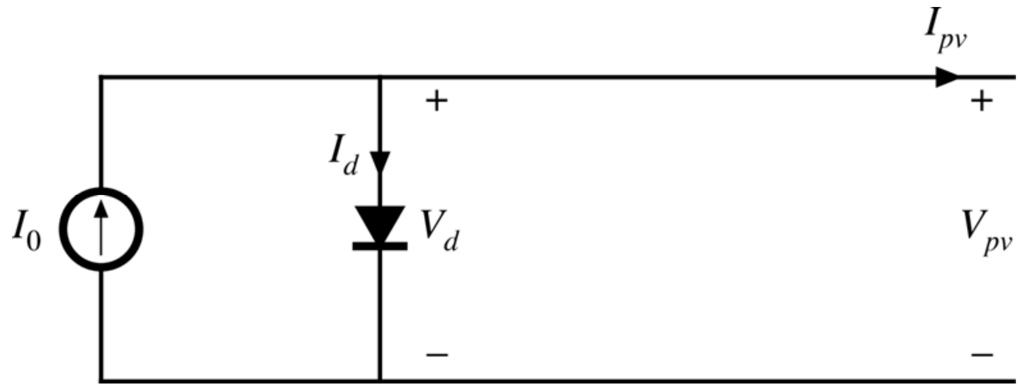
Current source I_0 models photo-generated current

I_0 is proportional to the *solar irradiance*, also called the "*insolation*":

$$I_0 = k\ (\textit{solar irradiance})$$

Solar irradiance is measured in W/m^2

Development of Electrical Model of the Photovoltaic Cell, slide 3

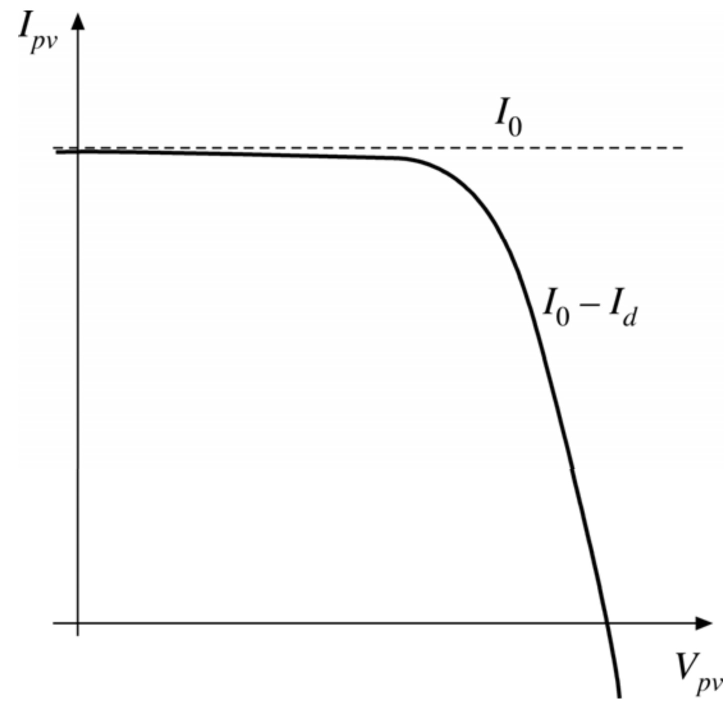


Diode models *p–n* junction

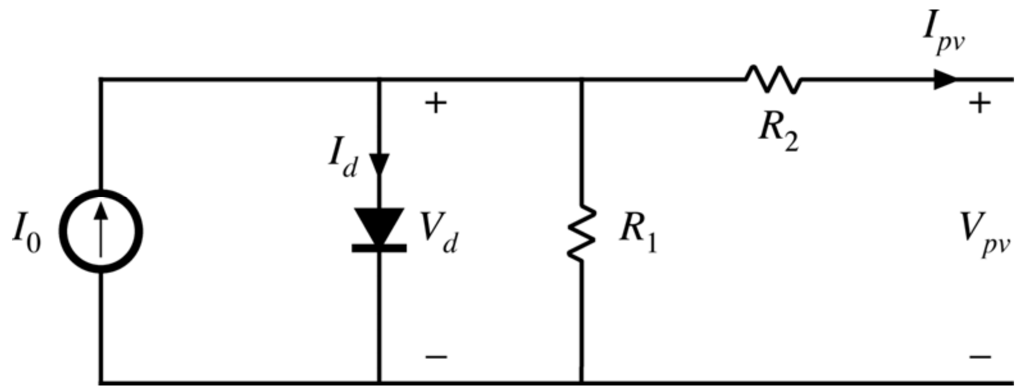
Diode *i–v* characteristic follows classical exponential diode equation:

$$I_d = I_{dss}\,(e^{\lambda V_d} - 1)$$

The diode current I_d causes the terminal current I_{pv} to be less than or equal to the photo-generated current I_0.



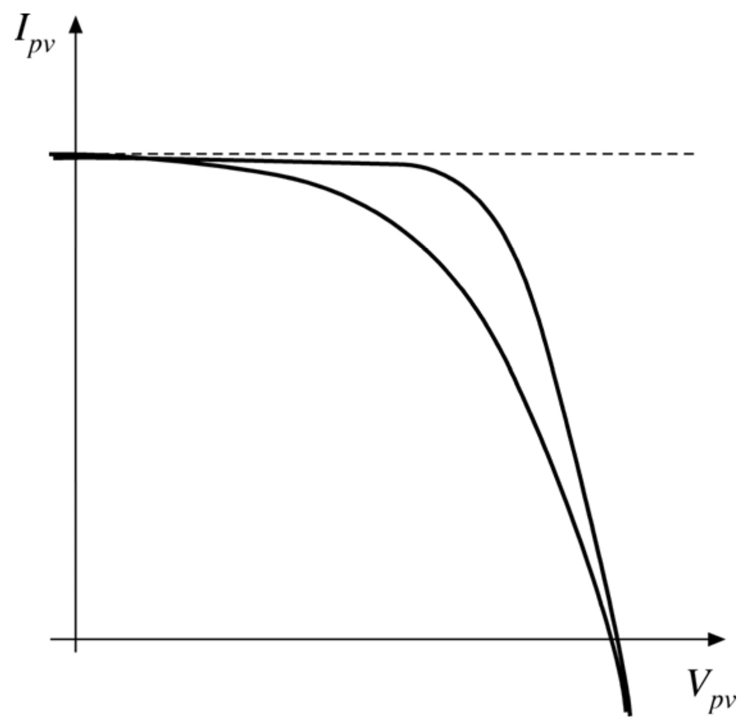
Development of Electrical Model of the Photovoltaic Cell, slide 4



Modeling nonidealities:

R_1 : defects and other leakage current mechanisms,

R_2 : contact resistance and other series resistances



Cell characteristic

Cell output power is $P_{pv} = I_{pv}V_{pv}$

At the maximum power point (MPP):

$V_{pv} = V_{mp}$

$I_{pv} = I_{mp}$

At the short circuit point:

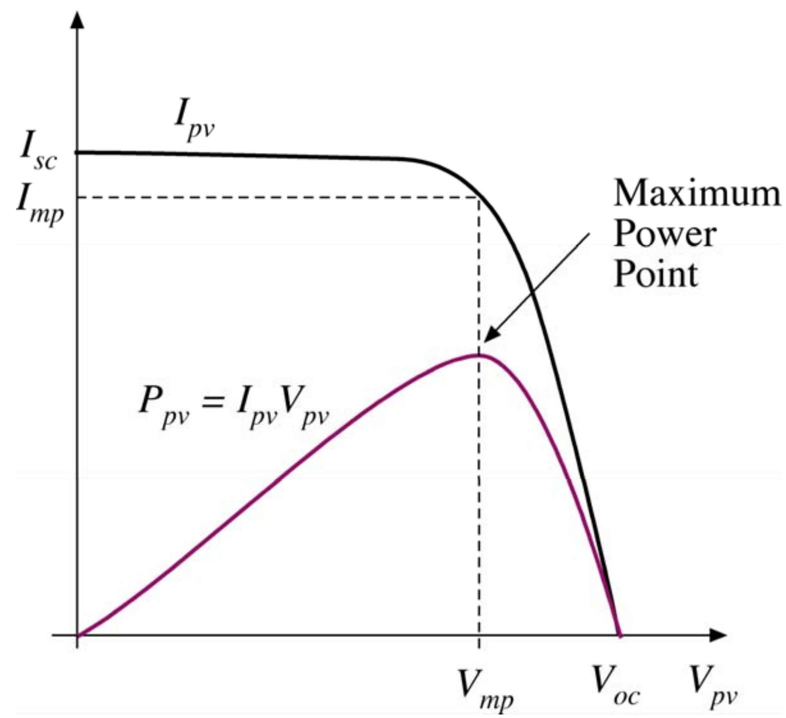
$I_{pv} = I_{sc} = I_0$

$P_{pv} = 0$

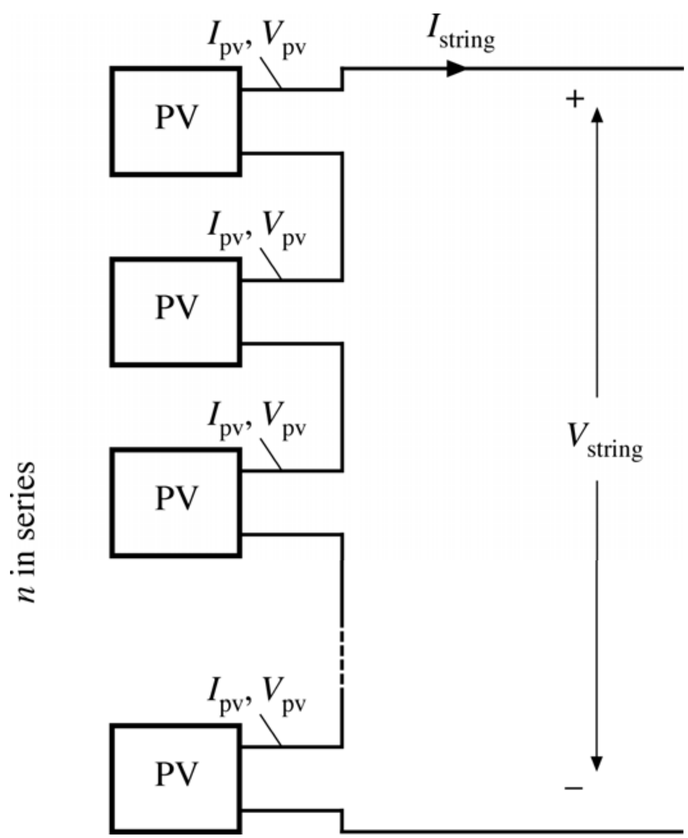
At the open circuit point:

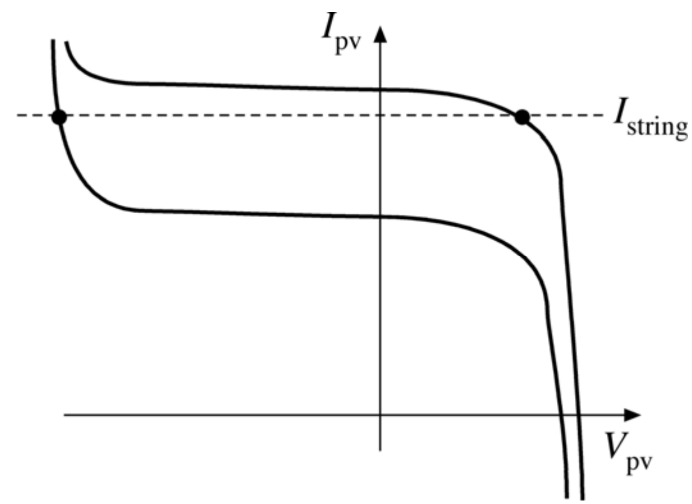
$V_{pv} = V_{oc}$

$P_{pv} = 0$



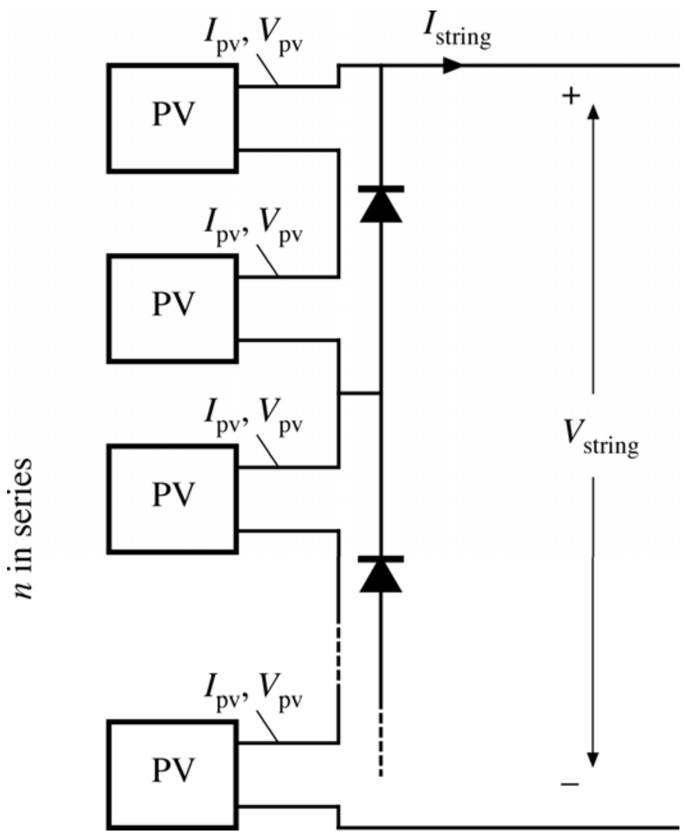
Series String of PV Cells
to increase voltage

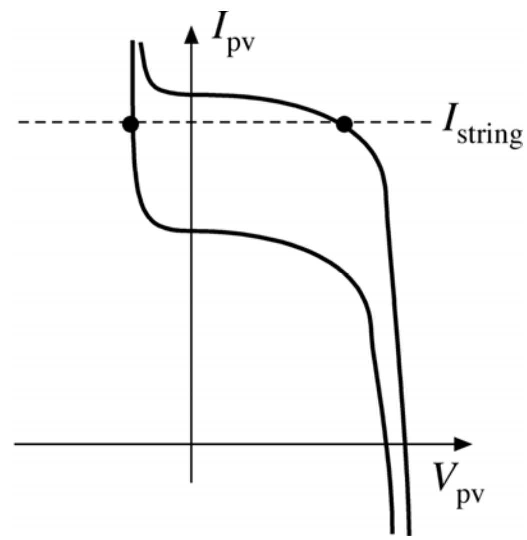




- To increase the voltage, cells are connected in series on *panels*, and panels are connected in series into *series strings*.
- All series-connected elements conduct the same current
- Problems when cells irradiance is not uniform

Bypass Diodes

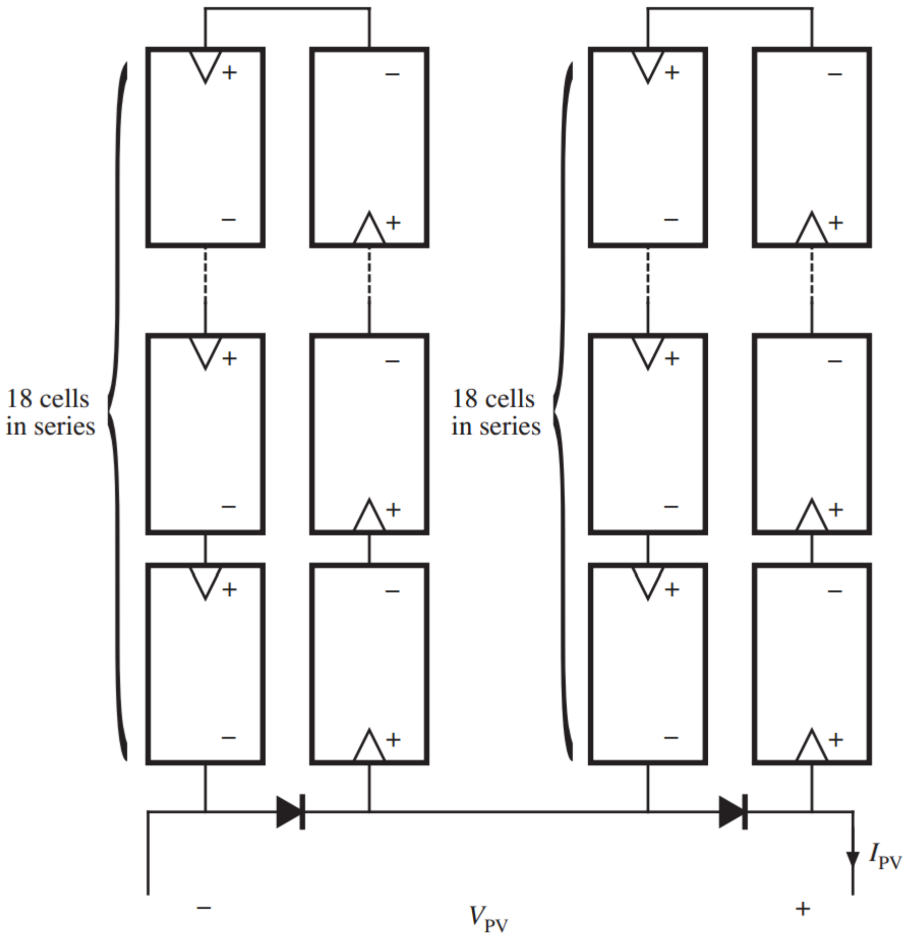




Bypass diodes:

- Limit the voltage drop across reverse-biased cells or strings of cells
- Reduce the power consumption of reverse-biased cells

Lab PV panel: SQ85-P

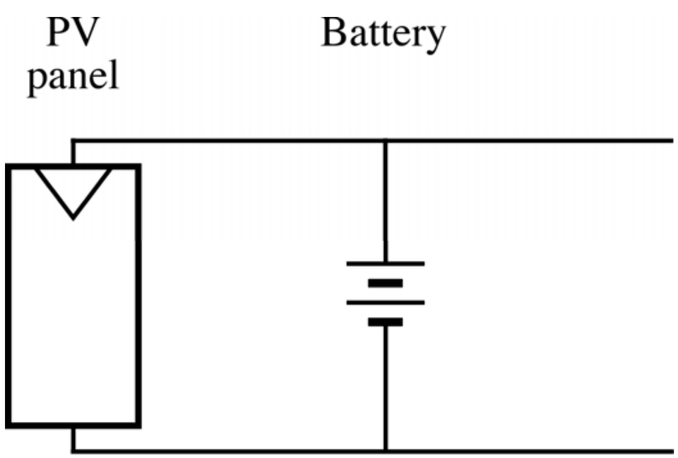


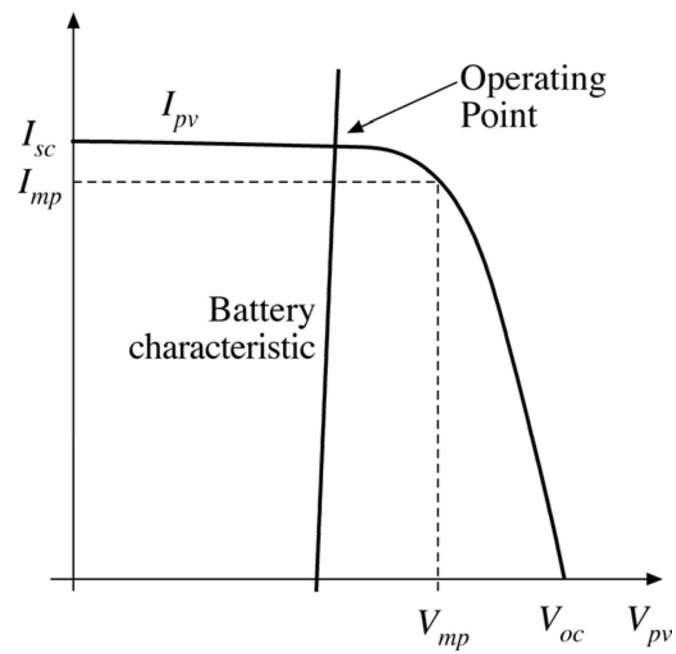
Exp 1:

- Measure PV panel characteristics and determine circuit model parameters
- Effects of shading

36 cells in series, arranged in two substrings of 18 cells, with 2 backplane diodes

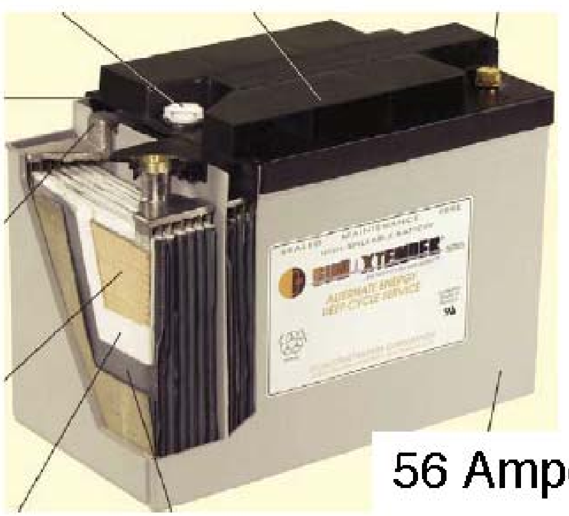
Exp 1: Direct Energy Transfer



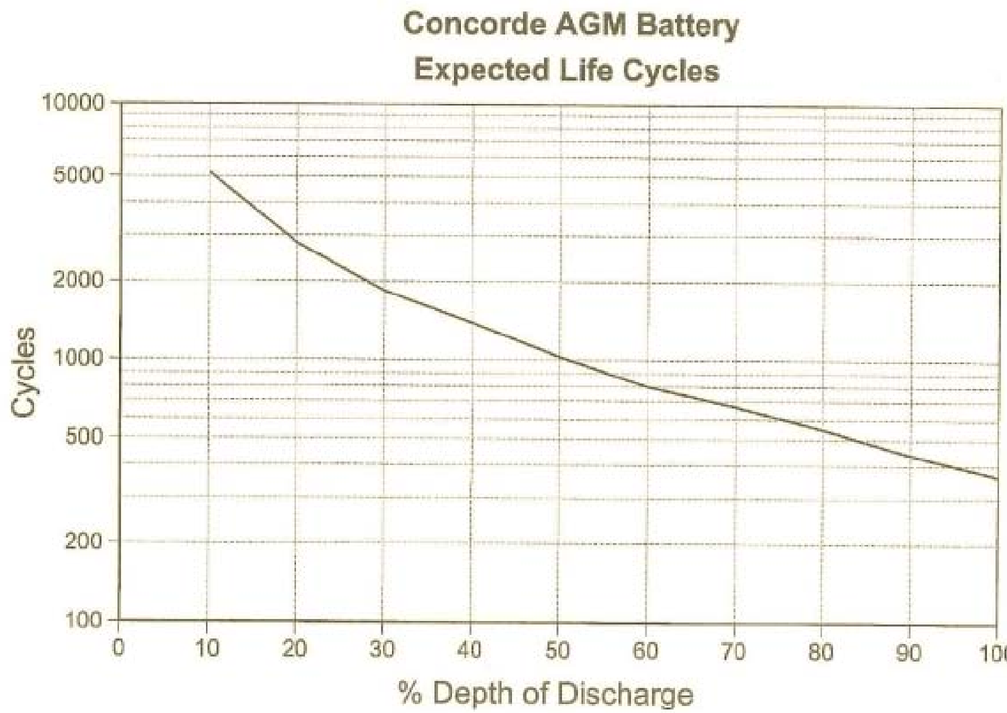


Lab deep-discharge lead-acid battery

- Theory and modeling of batteries
- Don't overcharge: this causes outgassing and can quickly ruin the battery
- Don't discharge below 50% SOC: this reduces battery life



56 Ampere-hour



Battery state of charge (SOC) vs. terminal voltage

100% SOC	12.80 volts or greater
75% SOC	12.55 volts
50% SOC	12.20 volts
25% SOC	11.75 volts
0% SOC	10.50 volts

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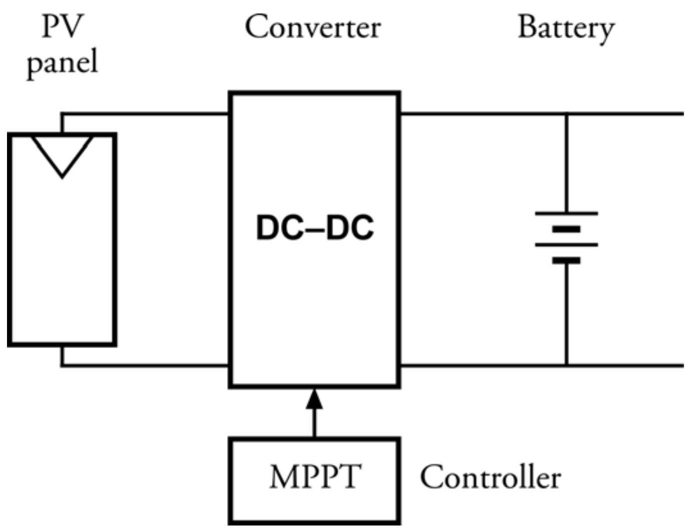
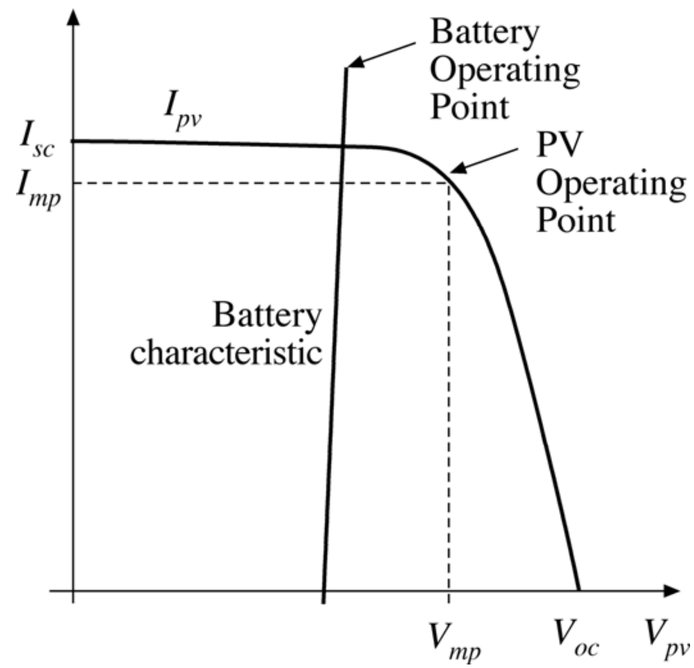
Exp 2-3: Maximum Power Point Tracking (MPPT)





- MPPT adjusts DC-DC converter conversion ratio $M(D) = V_{batt}/V_{pv}$ such that the PV panel operates at its maximum power point.
- The converter can step down the voltage and step up the current.
- Battery is charged with the maximum power available from the PV panel.