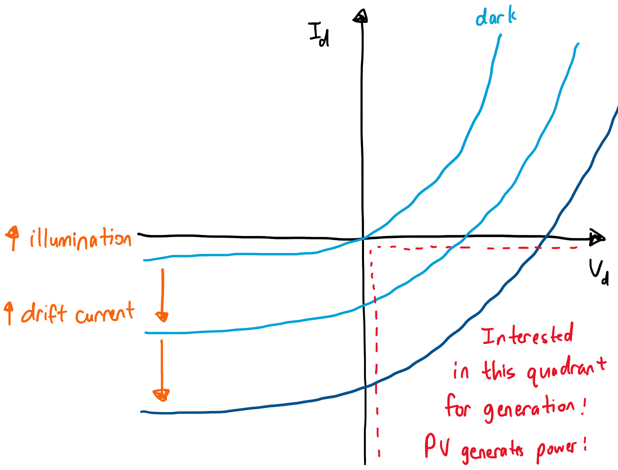
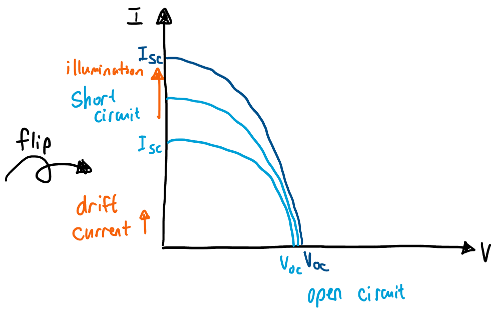
# PN Junction Circuit

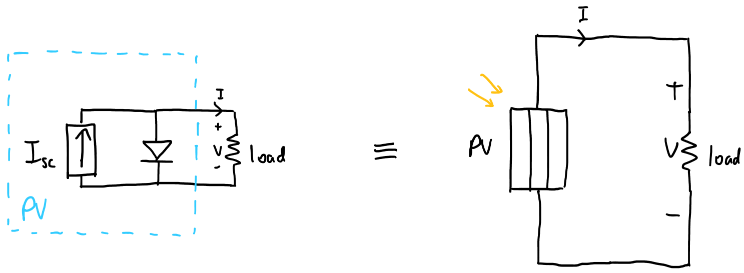
Thursday, February 15, 2024 3:59 PM




$I_{sc} \propto$ solar intensity

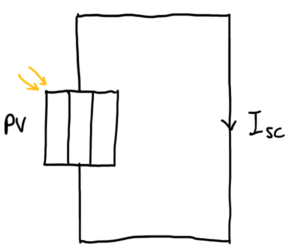
- A useful circuit to describe this behaviour




- From this model, $I = I_{sc} - I_d = I_{sc} - I_0\left(e^{\frac{qV_d}{kT}} - 1\right)$ at 25°C (often used as standard).

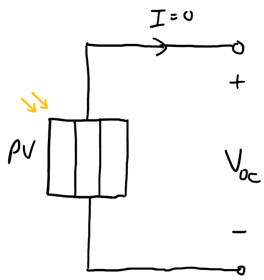
$$I_d = I_0\left(e^{38.9V} - 1\right)$$

- 2 important characteristics of PV cell




Short-circuit current

set $V = 0$, $I = I_{sc}$




Open-circuit voltage

set $I = 0$

$$\frac{I_{sc}}{I_0} = e^{\frac{qV_{oc}}{kT}} - 1$$

$$\frac{qV_o}{kT} = \ln\left(\frac{I_{sc}}{I_0} + 1\right)$$

$$V_{oc} = \frac{kT}{q}\ln\left(\frac{I_{sc}}{I_0} + 1\right)$$

• Ex. 150 $cm^2$ PV cell with reverse saturation current $I_o = 10^{-12}\ A/cm^2$. In "full sun" ($1\ kW/m^2$), it produces short-circuit current of $40\ mA/cm^2$ at 25°C. What is $I_{sc}$, $V_{oc}$?

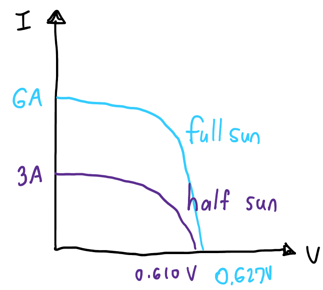
$$I_{sc} = 0.04 \times 150 = 6\ A$$

$$V_{sc} = \frac{kT}{q} \ln\left(\frac{I_{sc}}{I_o} + 1\right) = 0.0257 \ln\left(\frac{6}{10^{-12} \times 150} + 1\right) = 0.627\ V$$

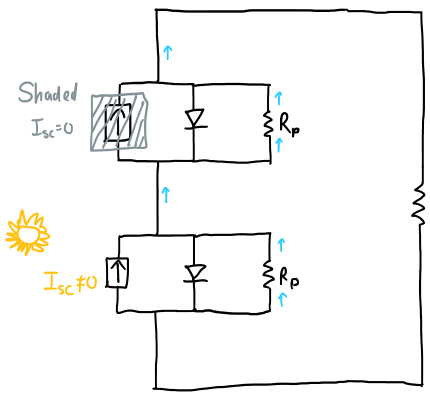
What about for "half sun?"

$$I_{sc} = 3\ A$$

$$V_{sc} = 0.610\ V$$




• More accurate circuit models of PV cell



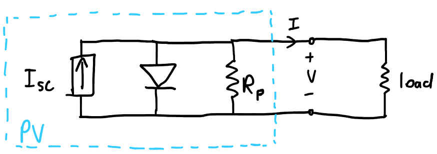

• For meaningful output voltage, connect PV cells in series

• In reality, there is current that goes to load

→ Add leakage resistance in parallel

• This way, current can pass through the shaded cell

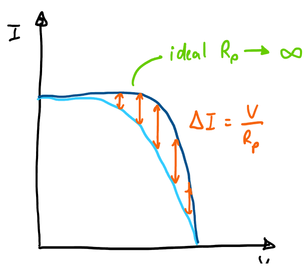
• Updated circuit model

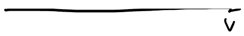



$$I = I_{sc} = I_d - \frac{V}{R_p}$$

• typically, in this model $R_p$ is large.

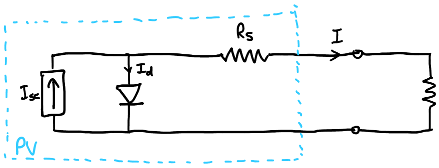
• allows small amount of current to pass





- Add $R_s$ in series to model contact resistance between cells/wires

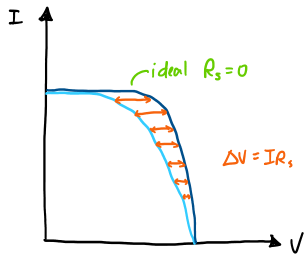
- Updated PV model with $R_s$



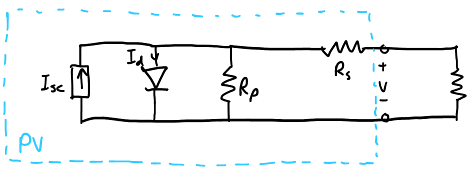

$$I = I_{sc} - I_d$$

$$I = I_{sc} - I\left(e^{\frac{qV}{kT}} - 1\right)$$

$$V_d = V + IR_s$$




- Updated equivalent circuit model with $R_p$ and $R_s$




$$I = I_{sc} - I_d - \frac{V_d}{R_p}$$

$$= I_{sc} - I_0\left(e^{\frac{qV_d}{kT}} - 1\right) - \frac{V_d}{R_p}$$

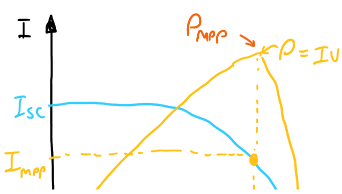
$$V_d = V + IR_s$$

$$I = I_{sc} - I_0\left(e^{\frac{q(V+IR_s)}{kT}} - 1\right) - \frac{V+IR_s}{R_p}$$

> Complicated! No explicit solution for $V$ or $I$

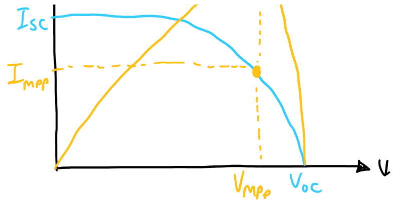
- <u>Maximum Power Point</u>

Important Characteristics : 1) $I_{sc}$ 2) $V_{oc}$ 3) $P_{MPP}$



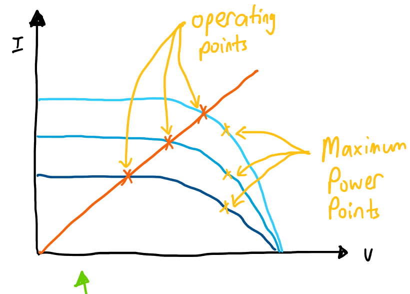

$$\boxed{\text{Fill Factor}} = \frac{P_{MPP}}{V_{oc}\, I_{sc}}$$

Best Commercial Cell: $FF \cong 0.7$

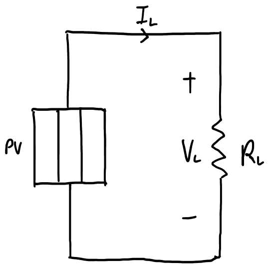


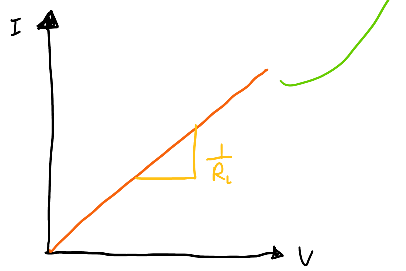

Best Commercial Cell: FF $\cong$ 0.7

- Factors that affect I-V curve
  1) Solar Irradiance
  2) Temperature
  3) Shading

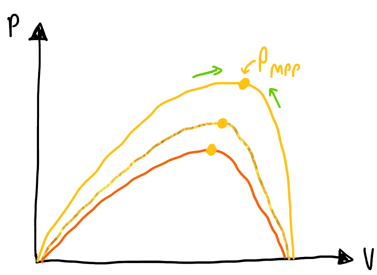



Q What if we just connect a load $R_L$ at the output?



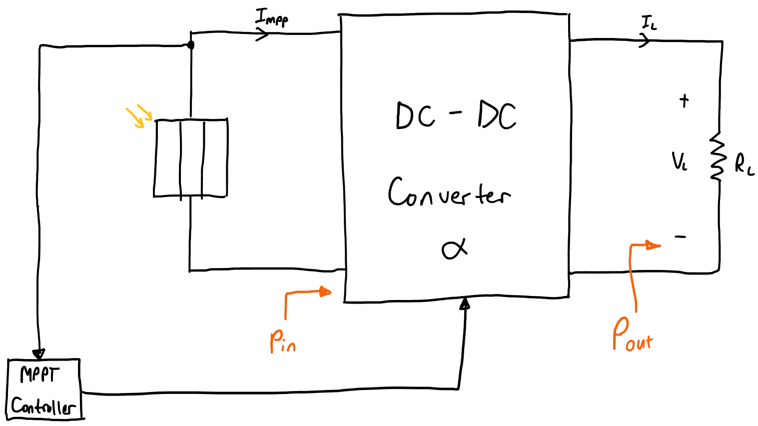

> $R_L$ is fixed, but in general $(V_L, I_L) \neq (V_{mpp}, I_{mpp})$
  ↳ don't want to connect PV directly to load
  ↳ want a circuit between PV and load
  ↳ "track" MPP




MPPT Controllers

- dozens of methods/algorithms
- e.g. Perturb & Observe
  - simple, okay for ideal case
  - oscillate around max power

- e.g. Incremental Conductance Model




$$V_L = \alpha V_{mpp}$$

$$P_{in} = P_{out}$$

$$V_L I_L = V_{mpp} I_{mpp}$$

$$\rightarrow I_L = \frac{1}{\alpha} I_{mpp}$$