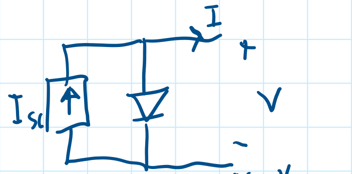
Today

Wednesday, April 15, 2020 9:06 AM

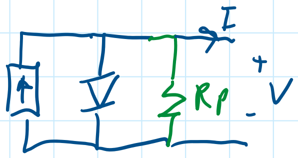
- Review
- From cells to modules
- From modules to arrays
- Maximum Power Point of a PV array
- Impacts of Temperature and Insolation on an V-I Curve

Review: Three different circuit models for a solar cell



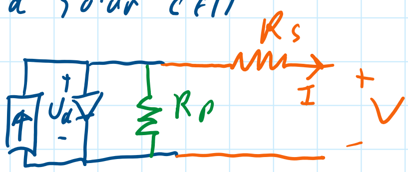
$I = I_{sc} - I_o(e^{qV/kT} - 1)$

Model #1



$I = I_{sc} - I_o(e^{qV/kT} - 1) - V/R_p$

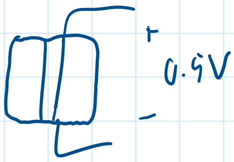
Model #2



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

Model #3

From the example at the end of last lecture, we saw that the open circuit voltage is around 0.6 V. When loaded, we can assume the terminal voltage is about 0.5 V.



=> ~240VAC, 480VAC, 800VAC → Grid

12 V, 24V, 48V - Battery storage

Instead of single cells, use multiple in an ARRAY
↳ series/parallel combination of cells encased in a weather resistant package

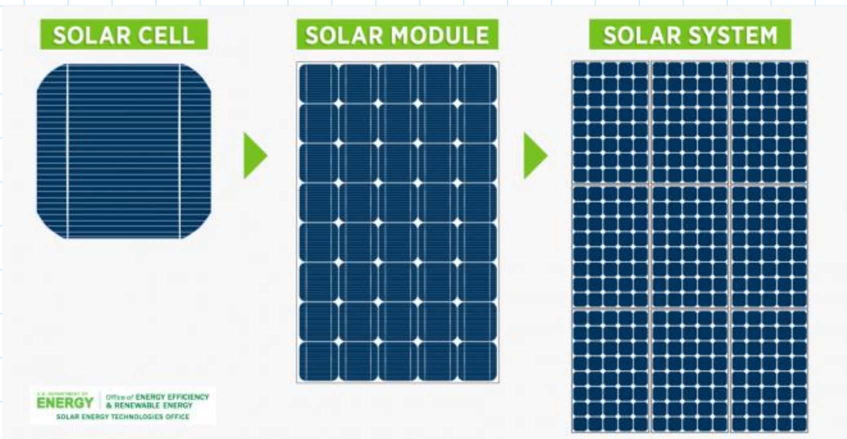


Photo credit: Energy.gov

From Cells to Modules

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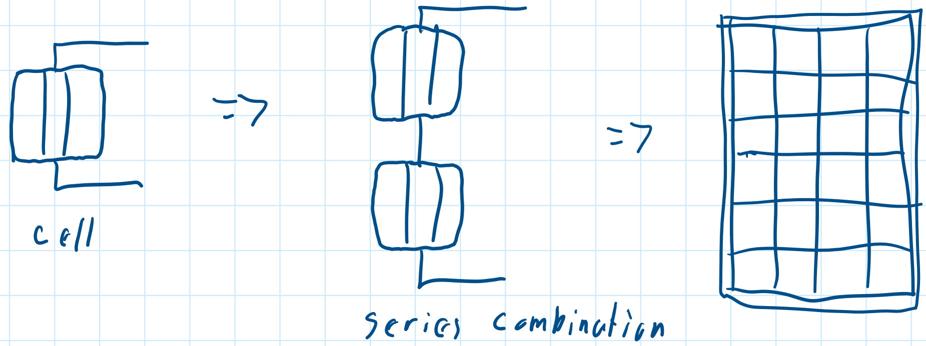
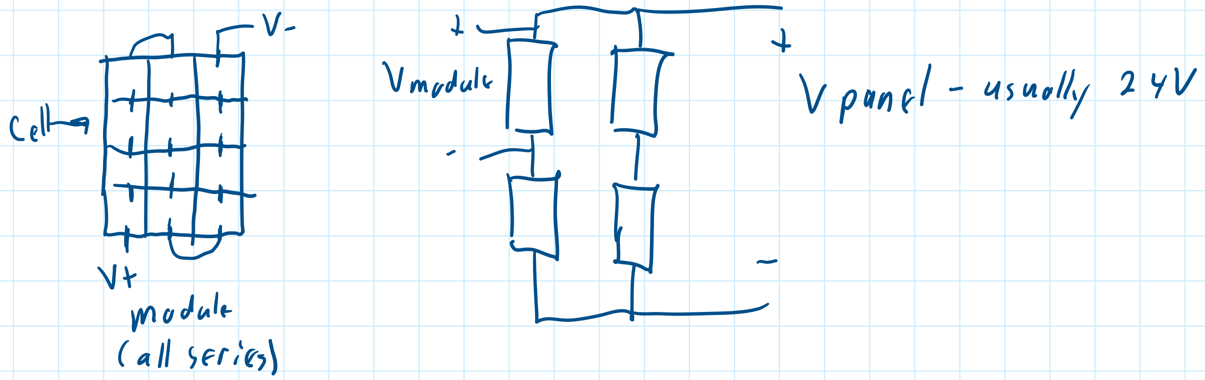
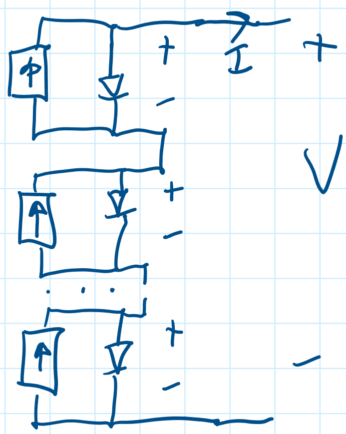


- Definition: Module - a series string of PC cells pre-wired and packaged together
- Modules/panels are made of cells
- 72, 96, and 128 cell modules are common today
- A solar panel is made of 1 or more modules, wired in series and/or parallel



V-I curve of a <u>Module</u>

Recall: $q/kT\big|_{298} = 38.9\ [1/V]$



Model #1

$$V = V_1 + V_2 + \dots V_n$$

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

For one cell:

$$I = I_{sc} - I_o\left(e^{38.9V} - 1\right)$$

$$\Rightarrow I_{sc} - I = I_o\left(e^{38.9V} - 1\right)$$

$$\Rightarrow e^{38.9V} = \frac{I_{sc} - I}{I_o} + 1$$

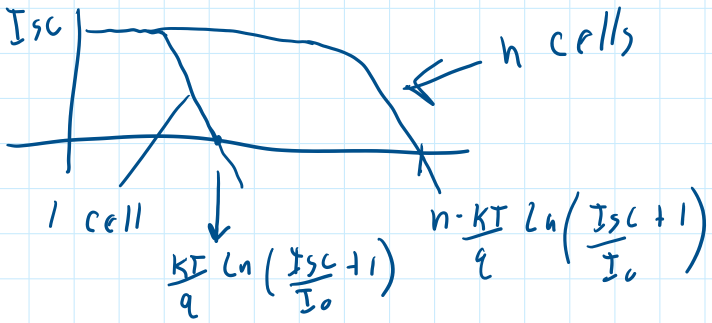
Assume no shading:

$$V_i = \frac{1}{38.9} \ln\left(\frac{I_{sc} - I + I_o}{I_o}\right)$$

assume $V_1 = V_2 = V_3 = \dots V_n$

$$V = n V_i$$

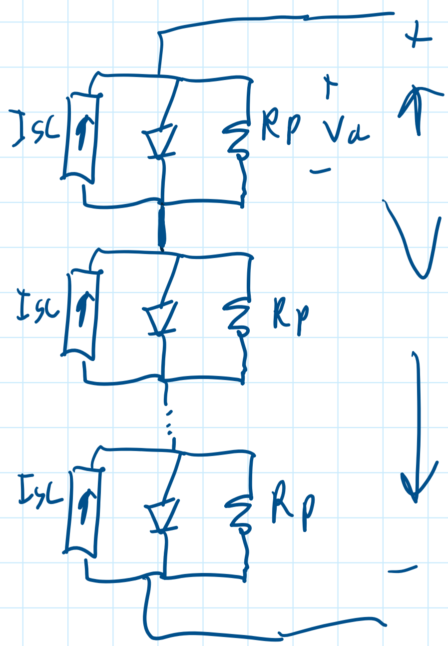
$$\Rightarrow V = n \frac{1}{38.9} \ln\left(\frac{I_{sc} - I + I_o}{I_o}\right) \Rightarrow I = I_{sc} - I_o\left(e^{38.9V/n} - 1\right)$$



This makes sense - like stacking batteries to get higher Voltage

note: $V_{oc} = n V_{i,oc}$

Now R_p?



Assuming no shading:

① $V = n V_d$

② $V_d = \frac{KT}{q} \ln\left(\frac{I_d}{I_o}+1\right)$

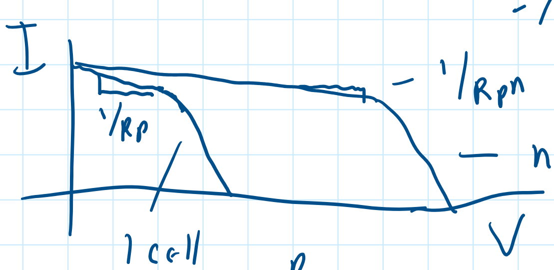
③ $I_d = I_{sc} - I - I_{RP}$

$= I_{sc} - I - V_d/R_p$

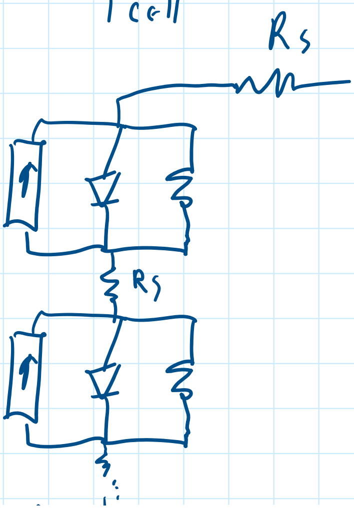
combine ①, ② & ③

$$V = n \frac{KT}{q} \ln\left(\frac{I_{sc} - I - V/nR_p}{I_o} + 1\right)$$

$$\Rightarrow I = I_{sc} - I_o\left(e^{38.9V/n} - 1\right) - \frac{V}{R_p \cdot n}$$



→ this slope is smaller



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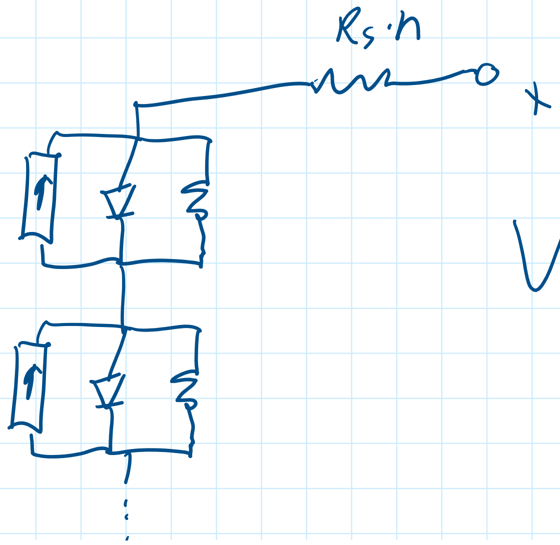
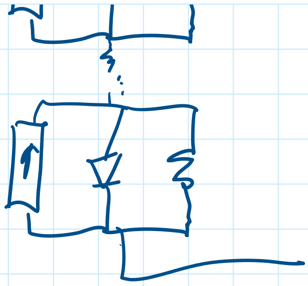
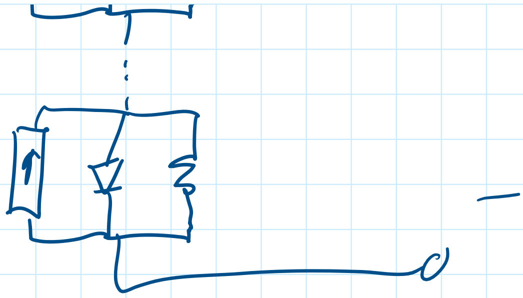
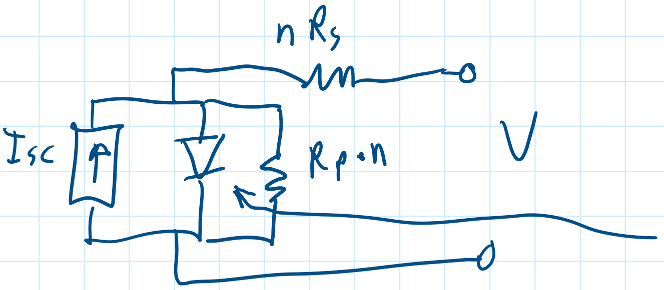






Again - Assuming no shading

Equivalent Model



this is a diode with characteristic:

$$I_d = I_0\, e^{(qV/nKT - 1)}$$

$$I = I_{sc} - I_o\left(e^{q/nkT\,(V + nR_s \cdot I)} - 1\right) - \frac{V + nR_s I}{n \cdot R_p}$$

From Modules to Arrays

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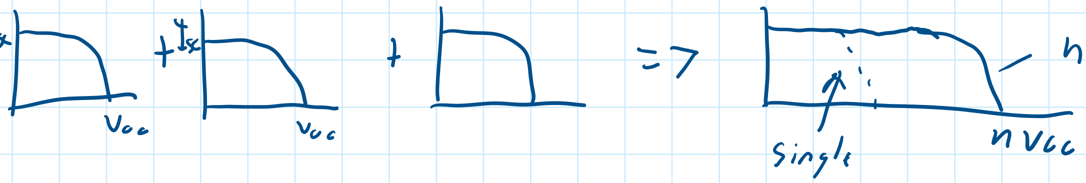
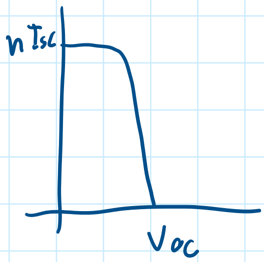
- We can see that modules can be wired in series to increase voltage, and in parallel to increase current
- In practice, arrays are made up of a combination of series and parallel modules
- From the previous analysis, we can see how we can obtain V-I curves for any given parallel/series combination

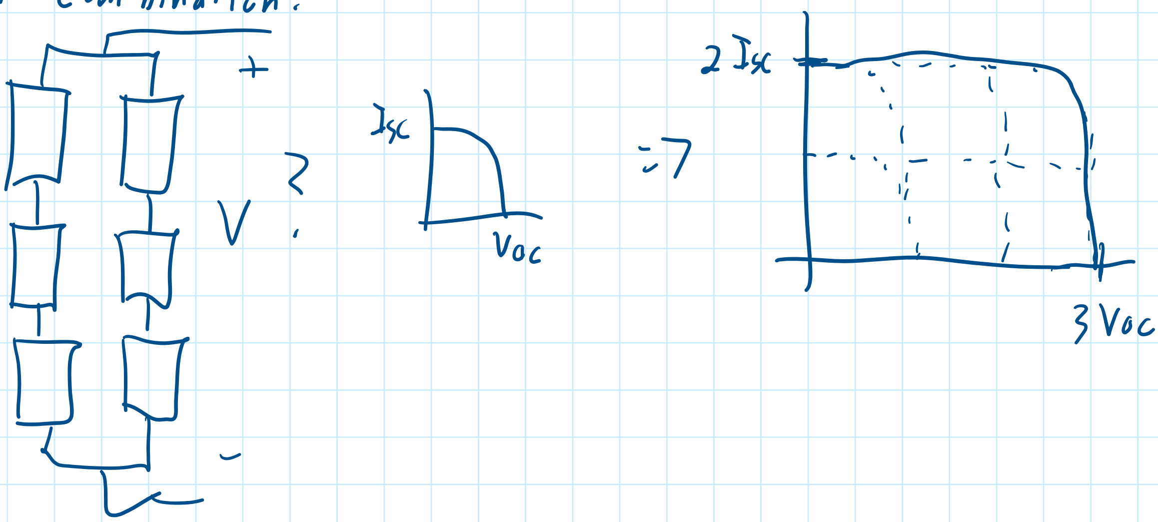
Series combination



parallel

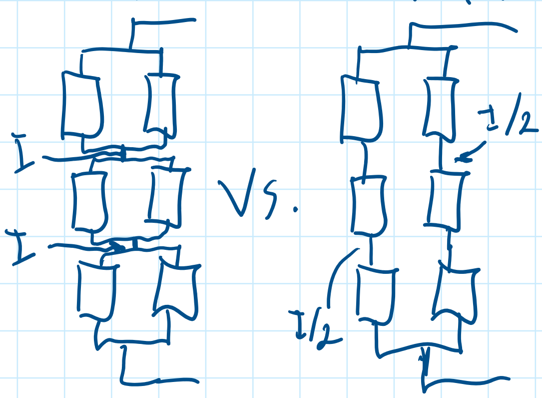


what about combination?



ways to wire

i) parallel first, then series (parallel/series)
ii) series then parallel (series / parallel)



sums I/V

→ the series/parallel is preferred

↳ can remove single string and still deliver same voltage

↳ minimizes interconnecting wires & I^2R losses

Maximum Power Point of a PV Array

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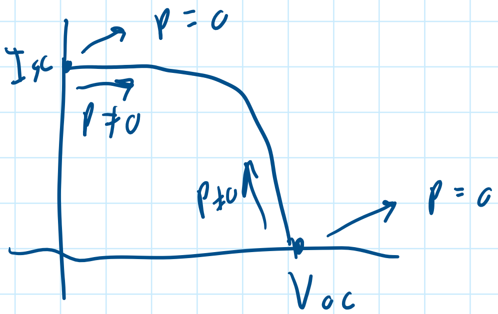


Question: what point on the curve extracts the most power from the cell/module/array?

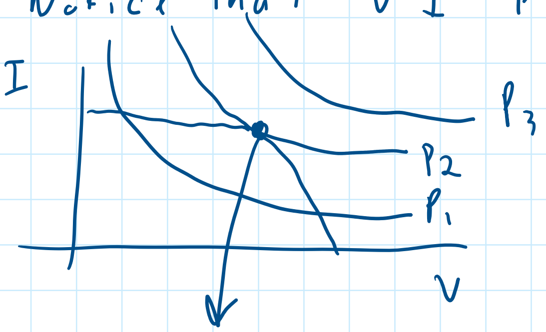
The hard way:

$$P = VI = V\left[I_{sc} - I_o e^{\frac{qV}{nkT}} - 1 \quad \ldots \right]$$

$$\frac{dP}{dV} = 0 \Rightarrow \ldots \text{ Math}$$

OR

Notice that $V \cdot I = P$



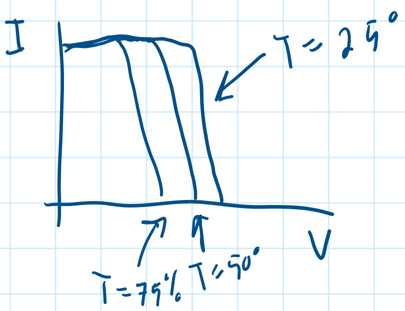
→ These curves are constant power

→ The maximum occurs for the curve that is tangent to the I-V curve at a single point

↳ this occurs at the knee of the solar I-V curve

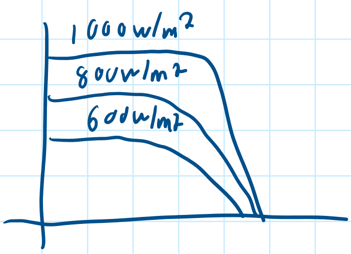
MPP - (maximum power point)

Impacts of temp. and Insolation on I-V curves



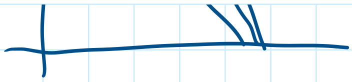
V_{oc} decreases ~ 0.33% per °C

I_{sc} only decreases ~ 0.05%



As insolation drops, short-circuit current drops in direct proportion. cutting insolation in half drops I_{sc} by half

Decreasing insolation also decreases V_{oc}, but only at a logarithmic rate. V_{oc}



Decreasing insolation also decreases V_{oc}, but only at a logarithmic rate. V_{oc} is only affected slightly

$\Rightarrow$ Solar cells work best on cold, clear days