Today

Monday, April 27, 2020 9:02 AM

Announcements:

- HW 10 Due Thursday - last HW of the semester!!!
- Final on Monday, 5/11/20 - similar to Exam 2
  - Take-home exam - 24 hours to complete
  - Should take you less than 3 hours to complete
  - Submission through Gradescope
  - Comprehensive, but more content on Solar material
  - Open book/note
  - Bonus points for including note sheet for content covered since Exam 2

Today: Solar PV Systems (Ch 6.1 - 6.3)

- PV system configuration
- Estimating System Performance
- AC & DC rated power
- The "peak hours" approach

PV system configuration

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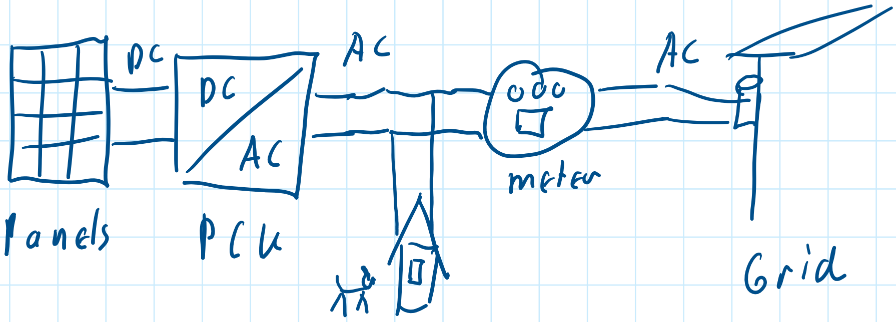
Components of a Grid-Connected System



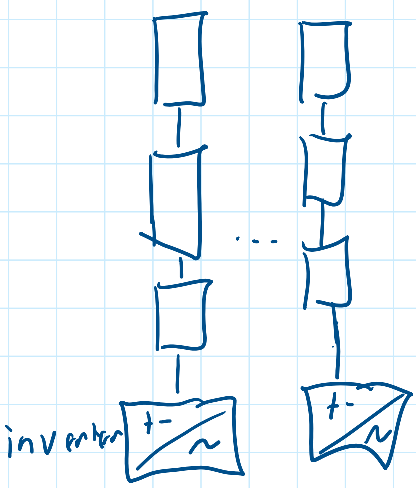
PCU
- ↳ MPPT
- ↳ Inverter (DC-AC
- ↳ ?

Question: Assume a line outage, what happens if the panels are still operating?

↳ PCU must include a shut-off / protection mechanism
  ↳ disconnects power if grid not connected

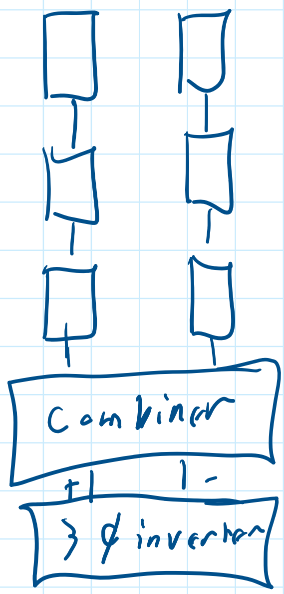
Inverter configuration

String Inverter



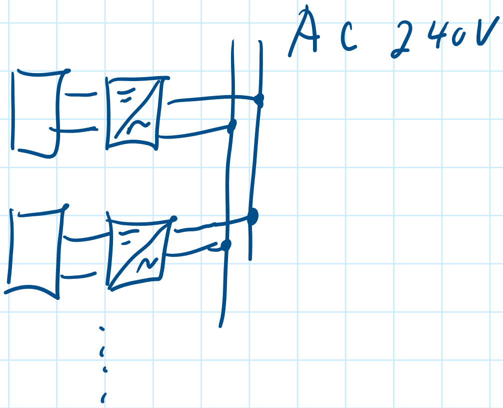
↳ roof top
  ↳ smaller installations

Central Inverter



↳ large installations
↳ utility scale

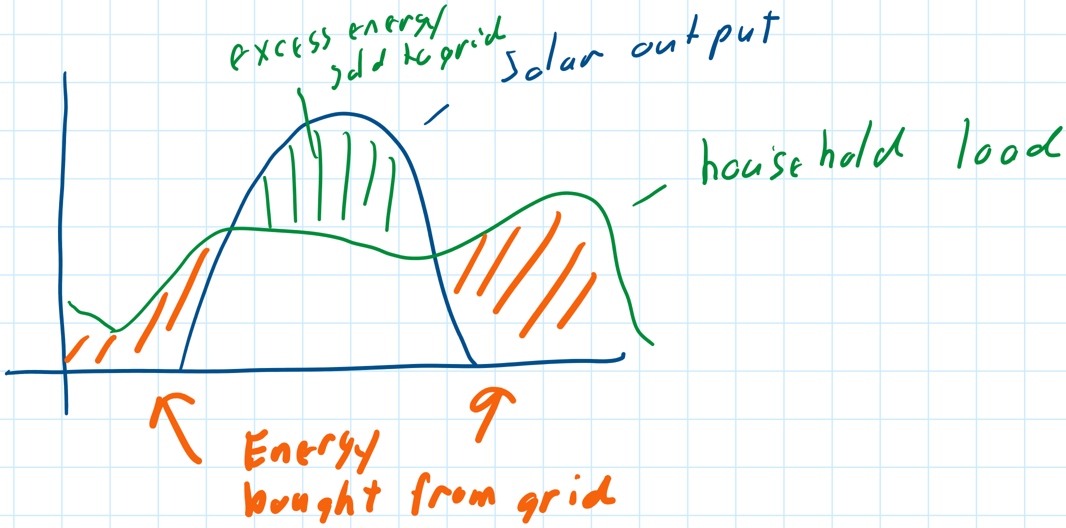
micro inverter



+ don't have to worry about shading effects
+ common household voltages/wiring
+ don't have to worry about panel mismatches
- higher upfront cost

Note: Net Metering

↳ For rooftop solar, PV system is behind the meter
 ↳ How does this work?



Net metering
↳ billing mechanism that credits solar energy system owners for energy injected into the grid
↳ customers only pay for electricity consumed that exceeds generation ⇒ the net energy
↳ implementation varies by jurisdiction

Estimating system performance

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How do we account for the system components?

- Start with DC rating of modules under STC
  - 1-sun
  - AM 1.5
  - T = 25°C
- Actual power given by

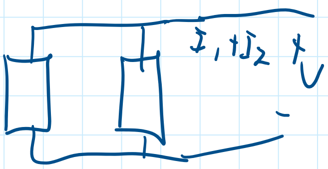
$$P_{ac} = P_{dc,STC} \cdot \eta$$

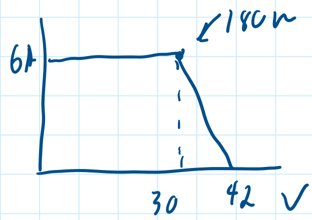
Where η is the conversion efficiency and includes

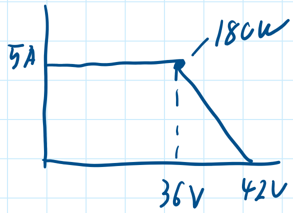
1. Mismatch module effects
2. Inverter efficiency
3. Dirty collector
4. Differences in ambient conditions

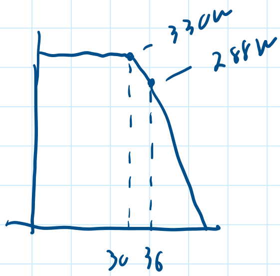
Mismatched Module Effects

Two modules in Parallel





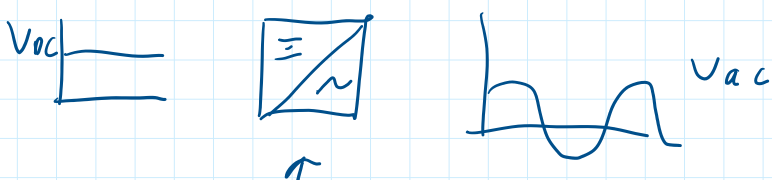




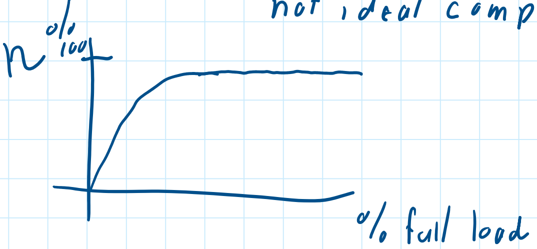
=> Since V_{mpp} is different for each panel, cannot achieve sum of two max powers

↳ this is actually pretty common due to manufacturing tolerances
=> same rated power, dif. I-V curve

Inverter Efficiency



not ideal components => losses



Good inverters reach efficiency up to 99% at full load
↳ this spec is a big deal for solar inverter Mfg.

Dirty Collector

↳ similar to partial shading
↳ reduces amount of insolation
↳ assumed to be uniform (no extra cell mismathes

Differences in Ambient Conditions

- Cell temp has a big impact
- in the field, cells are likely much hotter than 25°C
- we know that as T ↑, P ↓
- Instead of STC rating, PVUSA uses test conditions (PTC)

  ↳ 1-sun insolation
  20°C temp → ambient
  1 m/s wind

Derating a PV Array

Ex/ PV Array: $P_{dc} = 1\,kW$ (under STC)

- NOCT = 47°C (Nominal operating cell temperature when ambient temp is 20°C, S = 0.8 kW/m² and wind speed = 1 m/s)
- DC power at MPP drops by 0.5%/°C above STC temp 25°C
- 3% array loss due to mismatch modules
- 4% dirt losses
- 90% inverter efficiency

$$T_{cell} = T_{amb} + \left(\frac{NOCT - 20}{0.8}\right) \cdot S = 20 + \left(\frac{47-20}{0.8}\right) 1 = 53.8°C$$

$$P_{DC(PTC)} = 1\,kW\,(1 - 0.005(53.8 - 25)) = 0.856\,kW$$

$$P_{ac(PTC)}\ 0.856\,kW \cdot 0.97 \cdot 0.96 \cdot 0.9 = 0.72\,kW$$

↑ mismatch (0.97), ↑ dirt (0.96), ↑ inverter (0.9)

The peak hours approach

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- Predicting performance is also a matter of local insolation and temperature data
- We can combine the characteristics of the major components (PV Array and inverter) with insolation and temperature to obtain an estimate of the amount of electric power.
- If the units of daily, monthly, or annual average insolation are given in kWh/m^2-day, there is an easy way to interpret this number
- Recall: 1 sun of insolation is 1 kW/m^2
- Then, any given number of insolation, e.g., 3.4 kWh/m^2-day can be interpreted as 3.4 h/day of 1 sun insolation (peak sun)
- Thus, by knowing the amount of AC power delivered by the PV system under 1 sun, it is just a matter of multiplying by the number of peak sun hours per day.

Peak hours approach to energy-yield estimate

- Assume we have Pac for 1-sun insolation
- We want to find E (kWh/day) at a given site based on average insolation and temp. at the site
- S has units of $\frac{kWh}{m^2 \cdot day}$ (avg. insolation)

$\Rightarrow$ 3 kWh/m^2·day = $3\frac{h}{day} \cdot$ 1 kW/m^2 — 1 sun of insolation

$\Rightarrow$ An avg of 3 kWh/m^2·day of insolation is equivalent to having 3h/day of 1-sun insolation

E [kWh/day] = Pac × h/day of 1-sun insolation

- Let $\bar{\eta}$ be the average efficiency for the conversion stage

$$E\,(kWh/day) = S\left(\frac{kWh}{m^2 \cdot day}\right) \cdot A\,(m^2) \cdot \bar{\eta}$$

- For 1-sun insolation

$$P_{ac} = \underbrace{\left(\frac{1\,kW}{m^2}\right)}_{S_{1\text{-}sun}} \cdot A(m^2) \cdot \eta_{1\text{-}sun} \qquad S = x\left(\frac{h}{day}\right) \cdot S_{1\text{-}sun}$$

$$A\,(m^2) = \frac{P_{ac}}{S_{1\text{-}sun} \cdot \eta_{1\text{-}sun}}$$

$S_{1\text{-sun}} \cdot \eta_{1\text{sun}}$

$$E\,[\text{Kwh/day}] = X\left(\frac{h}{day}\right) \cdot S_{1sun} \cdot \frac{P_{ac}}{S_{1\text{-sun}} \cdot \eta_{1sun}} \cdot \bar{\eta}$$

$$E = X \cdot P_{ac} \cdot \bar{\eta} / \eta_{1sun}$$

if $\bar{\eta} / \eta_{1sun}$, then $E = X \cdot P_{ac}$

↳ this assumes system efficiency remains constant throughout the day
↳ ok assumption since system comes with MPPT

$P_{mpp} \propto S \Rightarrow \eta$ remains constant
(ignores temp effects)

Capacity factor for PV Grid connected systems

· Capacity factor describes % of time the system delivers full rated power

$$\text{Energy} = (\text{Kwh/yr}) = P_{ac}(\text{kw}) \cdot CF \cdot 8760\ \text{h/yr}$$

$$\text{capacity factor} = \frac{\text{h/day of "peak sun"}}{24\ \text{h/day}}$$

$$= \frac{\text{h of peak sun per day}}{24\ \text{h}}$$

Ex: $5.1 \frac{\text{Kwh}}{\text{m}^2\text{-day}}$

$$CF = \frac{5.1\ \text{h of peak sun/day}}{24\ \text{h}}$$

$$= 0.2125$$