13-PV System Design

ECEGR 452
Renewable Energy Systems

Overview

- Design Example
- Other PV Considerations

Stand Alone PV System Design

- Consider a simple design approach
- Part art, part science
- Steps:
    1. Develop Load Profile
    2. Determine Solar Resource
    3. Select Battery
    4. Select PV Array
    5. Select Controllers, etc

Design Example

- Stand-alone PV for a cabin
- Supply energy three days a week (long weekends)
- Located near Denver, CO

Design Example-Load

- Appliances (all rated for 12 V dc)
  - water pump
  - refrigerator
  - fans
  - lights
- All loads except the refrigerator are off four days a week

Design Example-Load

- Develop Load Profile for extremes: Summer and Winter
- Estimate hours of use per day in Summer and Winter
  - Consider occupied and unoccupied

Design Example-Load

- Occupied rates:

Appliance	Watts	Hr/day (Summer)	Hr/day (Winter)
Refrigerator	36	6.5	5
Water pump	25.2	9.3	7.4
Fans	15.5	9.3	0
Lights (Avg)	43.2	3.0	5.8

Design Example-Load

- Occupied average energy demand
  - Summer: 745 Wh/day
    - (36 x 6.5) + (25.5 x 9.3) +(15.5 x 9.3) + (43.2 x 3)
  - Winter: 620 Wh/day

Appliance	Watts	Hr/day (Summer)	Hr/day (Winter)
Refrigerator	36	6.5	5
Water pump	25.2	9.3	7.4
Fans	15.5	9.3	0
Lights (Avg)	43.2	3.0	5.8

Design Example-Load

- Unoccupied:
  - Summer: 234 Wh/day
  - Winter: 180 Wh/day

Appliance	Watts	Hr/day (Summer)	Hr/day (Winter)
Refrigerator	36	6.5	5
Water pump	25.2	0	0
Fans	15.5	0	0
Lights (Avg)	43.2	0	0

Design Example-Load

- Daily-averaged load each week:
  - Summer: ((3 x 745) + (4 x 234))/7 = 453 Wh/day
  - Winter: ((3 x 620) + (4 x 180))/7 = 369 Wh/day

Design Example: Battery Selection

- How large should the battery be?
- Depends on our sensitivity of risk vs cost
- Assuming worst case (no sun during occupation)
- Battery energy capacity:
  - Summer: 745 x 3 = 2235 Wh
  - Winter: 620 x 3 = 1860 Wh

Design Example: Battery Selection

- Non-ideality assumptions:
  - wiring efficiency: 98%
  - battery charge/discharge efficiency: 90%
  - battery winter temperature de-rating: 80%
  - battery maximum depth of discharge: 80%

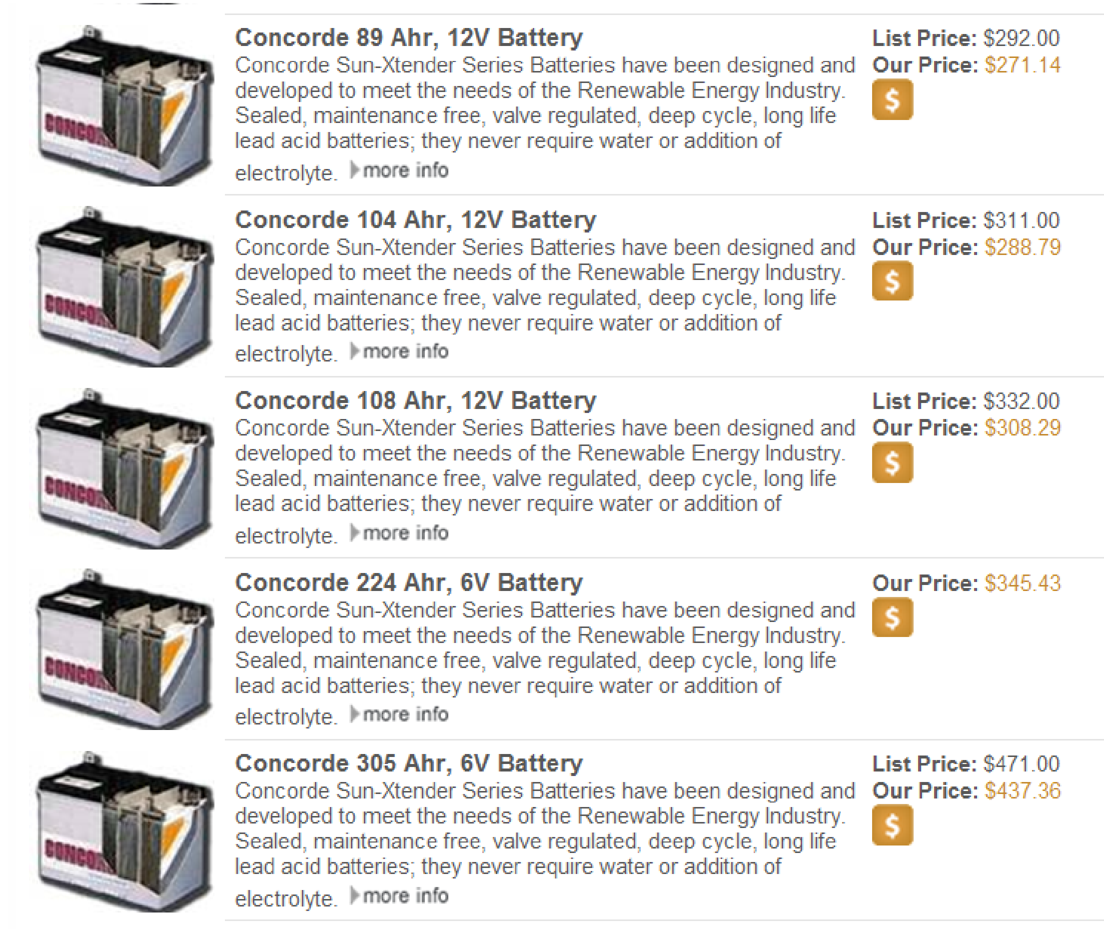
Design Example: Battery Selection

- Battery requirement:
  - Summer: 2235/.98/.9/.8 = 3168 Wh
    - 264 Ah @ 12 V
  - Winter: 1860/.98/.9/.8/.8 = 3295 Wh
    - 274 Ah @ 12 V
- Need energy storage of 274 Ah at 12 V
  - Also consider series and parallel combinations
- Consult a rechargeable battery catalog for options

Design Example: Battery Selection

- Consult supplier
- Possibilities
  - 4 Concorde 89Ah
  - 3 Concorde 104 Ah
  - 3 Concorde 108 Ah
  - 4 Concorde 224 Ah
  - 2 Concorde 305 Ah
- Minimal cost:

  3 x $288.79 = $866.37



Concorde 89 Ahr, 12V Battery
Concorde Sun-Xtender Series Batteries have been designed and developed to meet the needs of the Renewable Energy Industry. Sealed, maintenance free, valve regulated, deep cycle, long life lead acid batteries; they never require water or addition of electrolyte. more info
List Price: $292.00
Our Price: $271.14

Concorde 104 Ahr, 12V Battery
Concorde Sun-Xtender Series Batteries have been designed and developed to meet the needs of the Renewable Energy Industry. Sealed, maintenance free, valve regulated, deep cycle, long life lead acid batteries; they never require water or addition of electrolyte. more info
List Price: $311.00
Our Price: $288.79

Concorde 108 Ahr, 12V Battery
Concorde Sun-Xtender Series Batteries have been designed and developed to meet the needs of the Renewable Energy Industry. Sealed, maintenance free, valve regulated, deep cycle, long life lead acid batteries; they never require water or addition of electrolyte. more info
List Price: $332.00
Our Price: $308.29

Concorde 224 Ahr, 6V Battery
Concorde Sun-Xtender Series Batteries have been designed and developed to meet the needs of the Renewable Energy Industry. Sealed, maintenance free, valve regulated, deep cycle, long life lead acid batteries; they never require water or addition of electrolyte. more info
Our Price: $345.43

Concorde 305 Ahr, 6V Battery
Concorde Sun-Xtender Series Batteries have been designed and developed to meet the needs of the Renewable Energy Industry. Sealed, maintenance free, valve regulated, deep cycle, long life lead acid batteries; they never require water or addition of electrolyte. more info
List Price: $471.00
Our Price: $437.36

Design Example: Battery Selection

- Check data sheet for compatibility with assumptions

Design Example: Battery Selection

Sun Xtender® Battery		Overall Dimensions Inches (mm)			Unit Weight	Nominal Capacity Ampere Hours @ 25° C (77° F) to 1.75 volts per cell				
Part Number	Volts	Length	Width	Height	LB / KG	1 Hour Rate	2 Hour Rate	4 Hour Rate	8 Hour Rate	24 Hour Rate
PVX-340T	12	7.71 (196)	5.18 (132)	6.89 (175)	25 (11.4)	21	27	28	30	34
PVX-420T	12	7.71 (196)	5.18 (132)	8.05 (204)	30 (13.6)	26	33	34	36	42
PVX-490T	12	8.99 (228)	5.45 (138)	8.82 (224)	36 (16.4)	31	39	40	43	49
PVX-560T	12	8.99 (228)	5.45 (138)	8.82 (224)	40 (18.2)					
PVX-690T	12	10.22 (259)	6.6 (168)	8.93 (227)	51 (23.2)					
PVX-840T	12	10.22 (259)	6.6 (168)	8.93 (227)	57 (25.9)					
PVX-890T	12	12.9 (328)	6.75 (172)	8.96 (228)	62 (28.2)	55	70	72	79	89
PVX-1040HT	12	13.12 (333)	6.6 (168)	8.93 (227)	66 (30)	65	82	85	93	104
PVX-1040T	12	12 (304)	6.6 (168)	8.93 (227)	66 (30)	65	82	85	93	104
PVX-1080T	12	12.9 (328)	6.75 (172)	8.96 (228)	70 (31.8)	68				
PVX-2120L	12	20.76 (527)	8.63 (219)	8.63 (219)	138 (62.7)	13[illegible]				
PVX-2580L	12	20.76 (527)	10.89 (277)	9.77 (248)	165 (75)	165	209	214	236	258

Design is acceptable, even at 8 hour rate

$3 \times 93 = 279 > 274$

Energy Requirements

- Average daily energy required:
  - Summer: 453 x 1/.98 x 1/.9 = 514 Wh
  - Winter: 369 x 1/.98 x 1/.9 = 418 Wh
- Here we have assumed that all energy produced by the PV charges the battery (90% efficiency)

Solar Resource

- Solar resource data often given in $kWh/m^2/day$
- Total radiation (kWh) a square meter surface receives over the course of a day
- Often provided for different tilts
- Averaged over 1 month

Solar Resource

- Solar resource table:

Month	Tilt at Latitude -15º (kWh/m²/d)	Tilt at Latitude (kWh/m²/d)	Tilt at Latitude +15º (kWh/m²/d)
Dec	4.05	4.81	5.28
Jan	4.32	5.07	5.51
Feb	4.94	5.54	5.81
Jun	7.22	6.67	5.78
Jul	7.32	6.84	6.01
Aug	6.84	6.66	6.13

Solar Resource

- Values are equivalent to the number of hours per day the sun is shining at 1000 W/m^2
- Since PVs are rated at 1000 W/m^2, we can work directly with rated power
  - Assumes power output is linearly related to irradiance

$$P = P^*_{STC}\left(\frac{G}{G_{STC}}\right)$$

$$E = \int_{\omega_{sunrise}}^{\omega_{sunset}} P d\omega = \frac{P^*_{STC}}{G_{STC}} \int_{\omega_{sunrise}}^{\omega_{sunset}} G d\omega$$

$$E = \frac{P^*_{STC}}{G_{STC}} H$$

Solar Resource

- Example: a 30 W panel tilted at Latitude -15° in December would output (per day):

$$E = \frac{P^*_{STC}}{G_{STC}} H = \frac{30}{1000} 4050 = 121.5 \text{ Wh}$$

Month	Tilt at Latitude -15° (kWh/m²/d)	Tilt at Latitude (kWh/m²/d)	Tilt at Latitude +15° (kWh/m²/d)
Dec	4.05	4.81	5.28
Jan	4.32	5.07	5.51
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PV Size

- PV size can be found by dividing daily energy required by the daily solar radiation
- Example: for an array tilted at Latitude -15° in December would need to be rated at:

$$E = \frac{P^*_{STC}}{G_{STC}} H$$

$$418 = \frac{P^*_{STC}}{1000} 4050$$

$$P^*_{STC} = \frac{418 \times 1000}{4050} = 103 \text{ W}$$

PV Size

- Repeating the calculation

Month	Daily Energy Requirement (Wh)	Tilt at Latitude -15º PV Size (W)	Tilt at Latitude PV Size (W)	Tilt at Latitude +15º PV Size (W)
Dec	418	103	86.9	79.1
Jan	418	96.8	82.4	75.8
Feb	418	84.6	75.5	71.9
Jun	514	71.2	77.1	88.9
Jul	514	70.2	75.1	85.5
Aug	514	75.1	77.2	83.8

PV Size

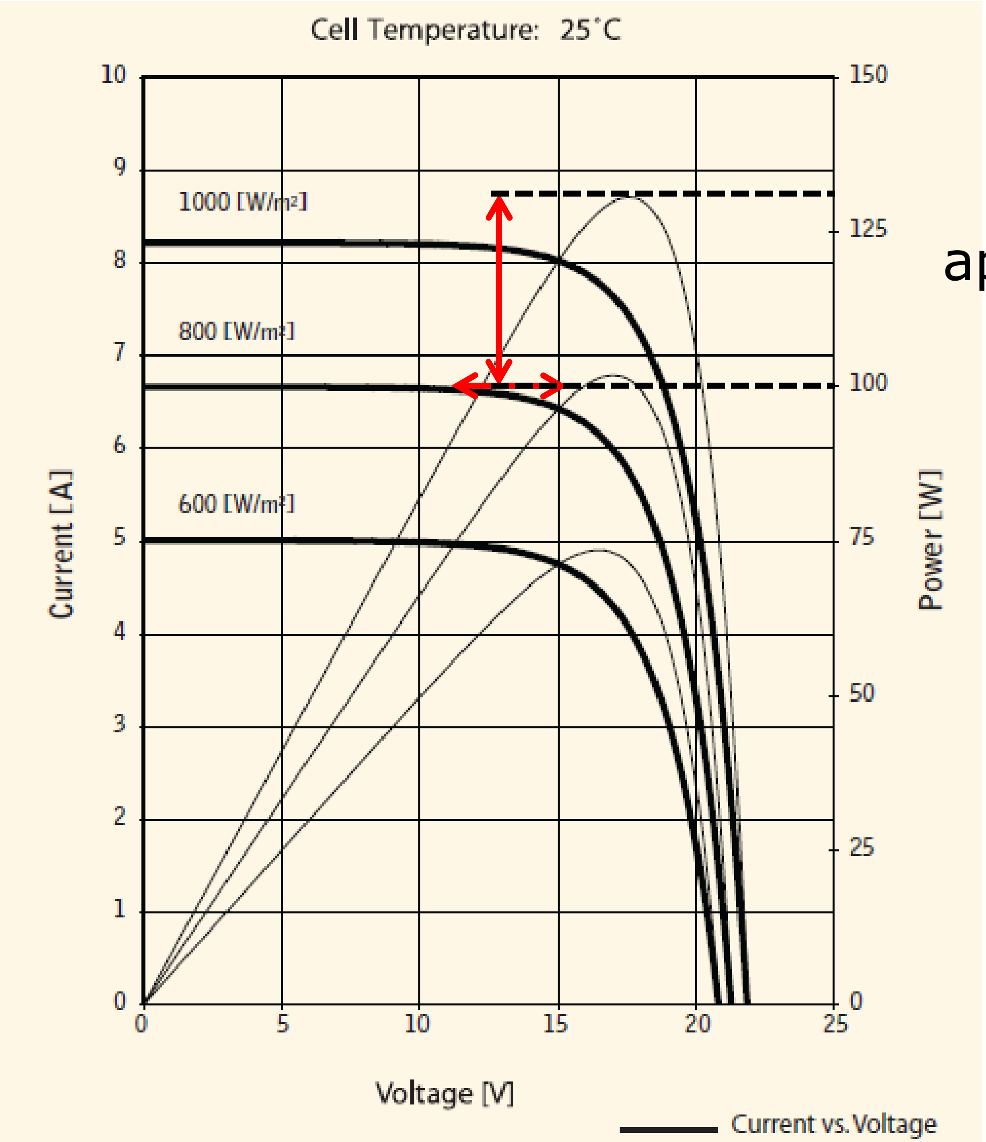
- What size and tilt should we use?

Month	Daily Energy Requirement (Wh)	Tilt at Latitude -15° PV Size (W)	Tilt at Latitude PV Size (W)	Tilt at Latitude +15° PV Size (W)
Dec	418	103	86.9	79.1
Jan	418	96.8	82.4	75.8
Feb	418	84.6	75.5	71.9
Jun	514	71.2	77.1	88.9
Jul	514	70.2	75.1	85.5
Aug	514	75.1	77.2	83.8

Select the minimum of maximums: 86.9 W

PV Array

- Apply a de-rating to account for temperature effects, losses, aging, non-MPP operation
  - PV de-rating factor: 65%
    - Do NOT use this value in HOMER
- PV array must supply 86.9 x (1/0.65) = 133 W
  - With MPP close to 15 V (charging voltage)
- consult PV supplier for options

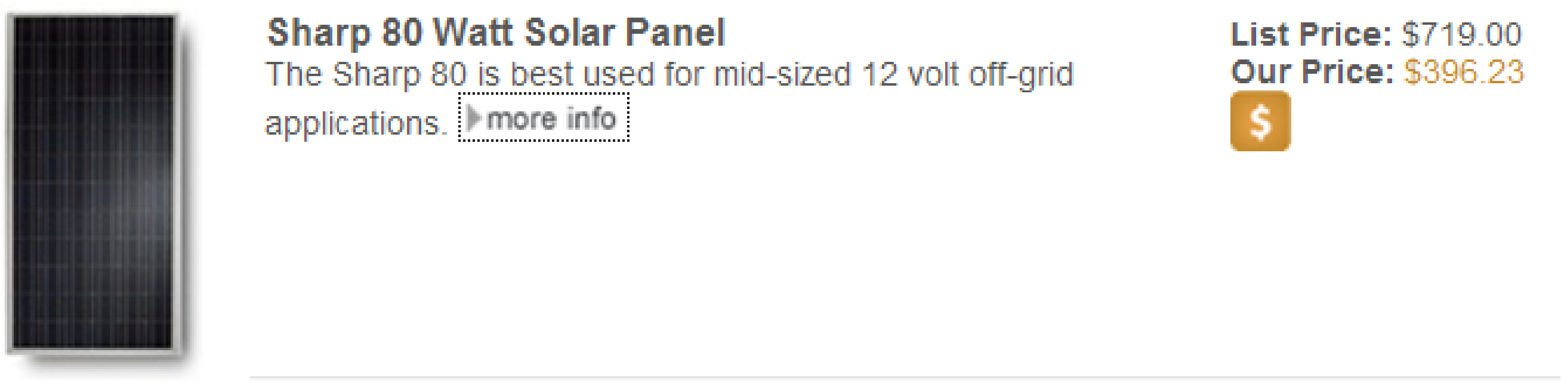


Current, Power vs. Voltage Characteristics

approx 75% decrease

PV Array

- 2 Sharp 80 W
  - 2 x $396.23 = 792.46
- This provides a safety factor of 160/135 = 1.19
- Place in parallel
- Verify with spec sheet



Controller

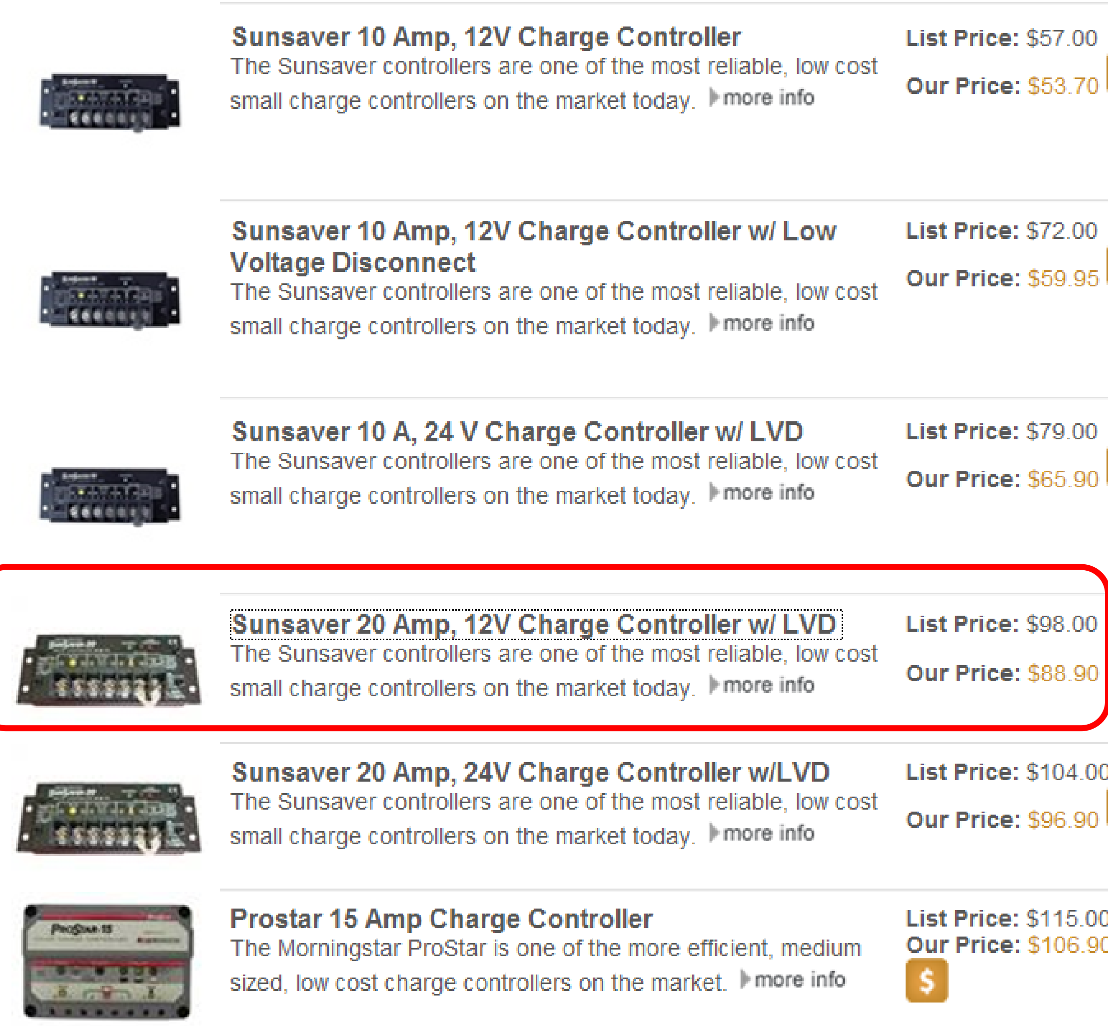
- Controller ratings
  - Solar Input (Amps)
  - Load (Amps)
  - Battery (Amps)
- PV short circuit current
  - 5.15 A each (from spec sheet)
- Load current
  - Assume all loads on at once
  - Rating must be maximum of:
    - Summer: 10 A
    - Winter: 8.7 A

Controller

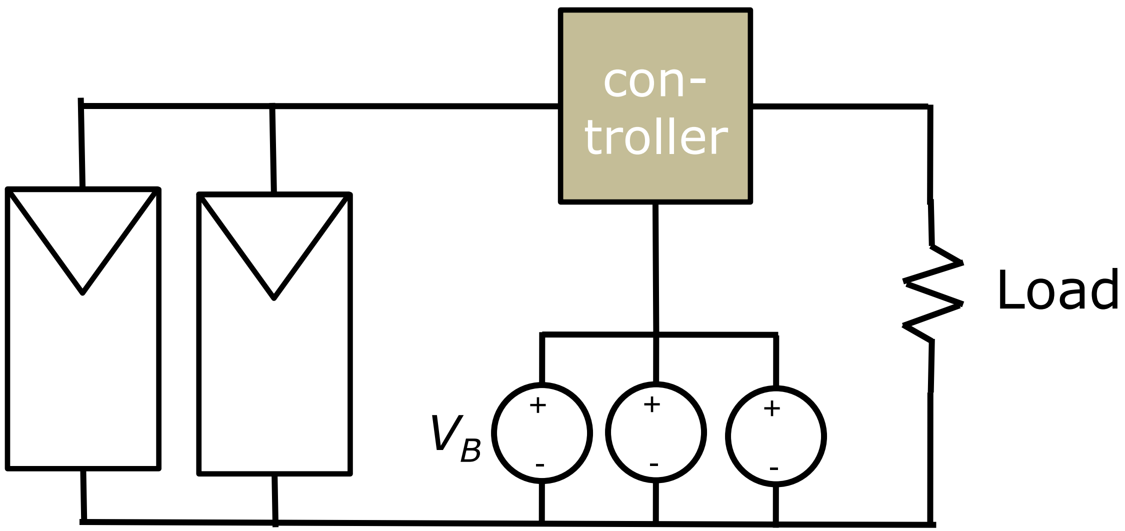
- Current to battery should be greater of PV current and load current
- Need a controller with:
  - Load rating: >10 A
  - PV rating: > 10.3 A
  - Battery: > 10 A
- Consult a charge controller catalog

Controller

- 20 A, 12 V Charge Controller
  - $88.90



Design



Design

- Equipment Cost:
  - \$866 + \$792 + \$89 = \$1747
- Taxes, shipping not included
- Fuses, wiring, structure for tilting, hardware, installation not included
- Consider that the average load is
  - Summer: 18.9 W
  - Winter: 15.4 W
- Very expensive!

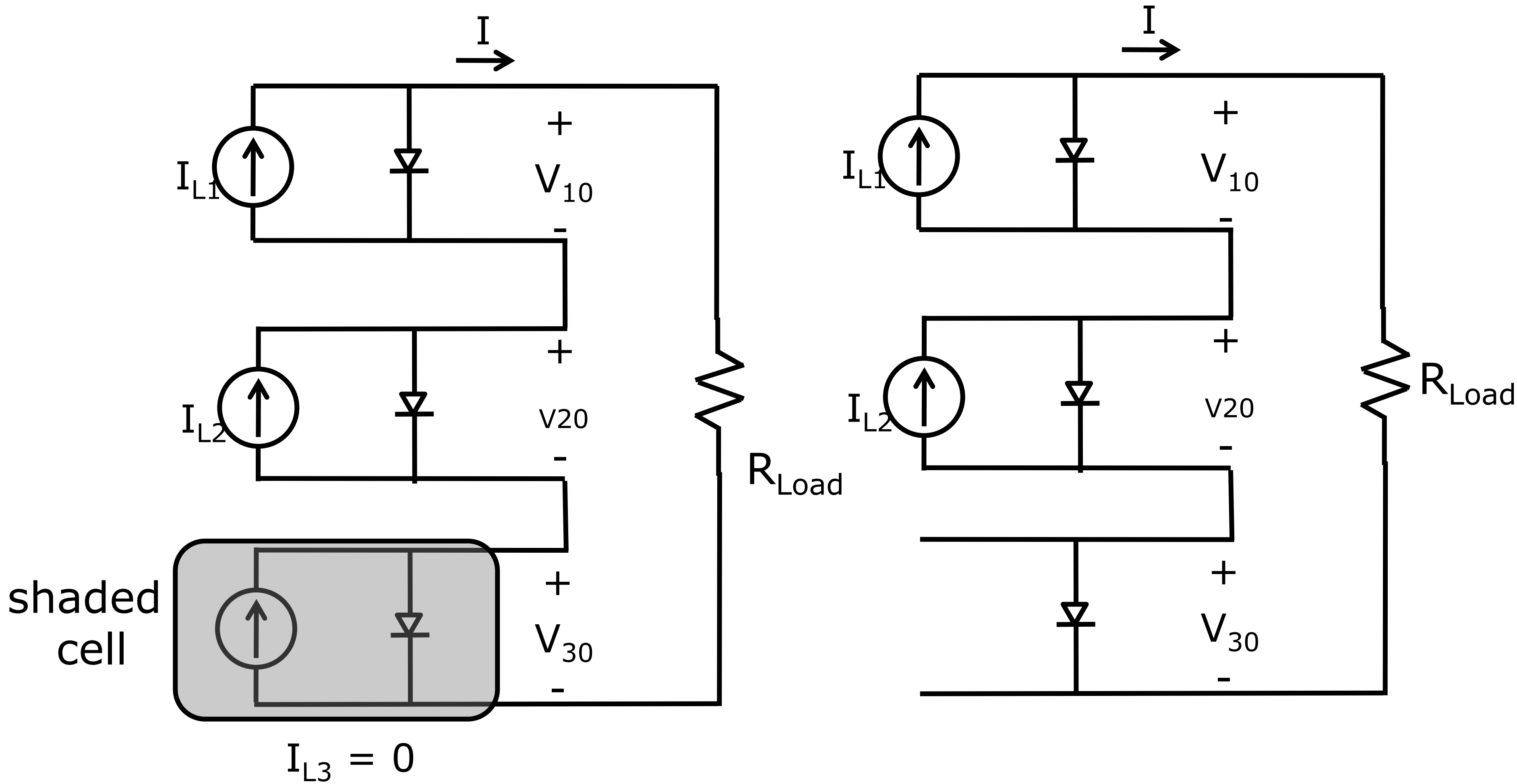
Design

- Other design approaches:
  - Use HOMER!
  - Compute PV array size based on current

Shading

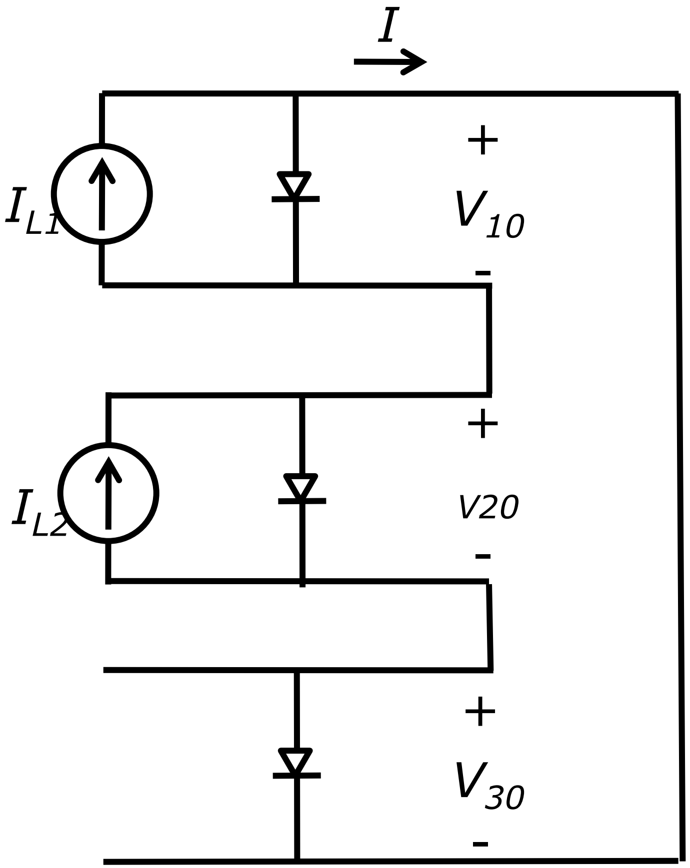
- What happens when a portion of a PV module is shaded?

Shading


I
I
IL1
+
V10
-
+
V20
-
IL2
RLoad
shaded cell
+
V30
-
IL3 = 0
I
IL1
+
V10
-
IL2
+
V20
-
RLoad
+
V30
-

Shading

- Voltage across shaded cell
  - $V_{30} = -V_{10} - V_{20}$
- Shaded cell is a reversed biased diode
- Power is <u>dissipated</u>
  - Overheating and damage can occur
- Output current is severely reduced



Shading

- Solution to shading is to use bypass diodes