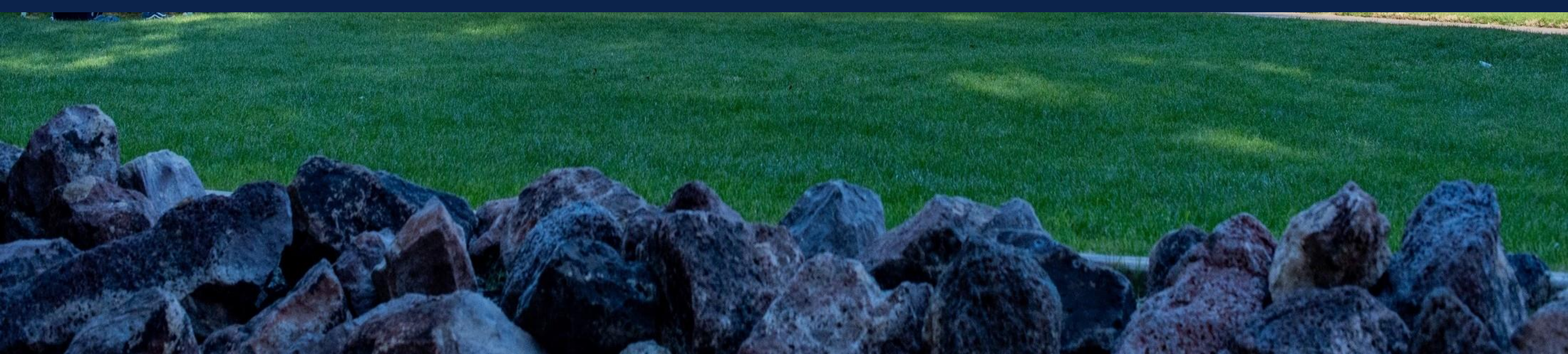
NSF NRT-InFEWS: Indigenous Food, Energy, and Water Security and Sovereignty
Presents:

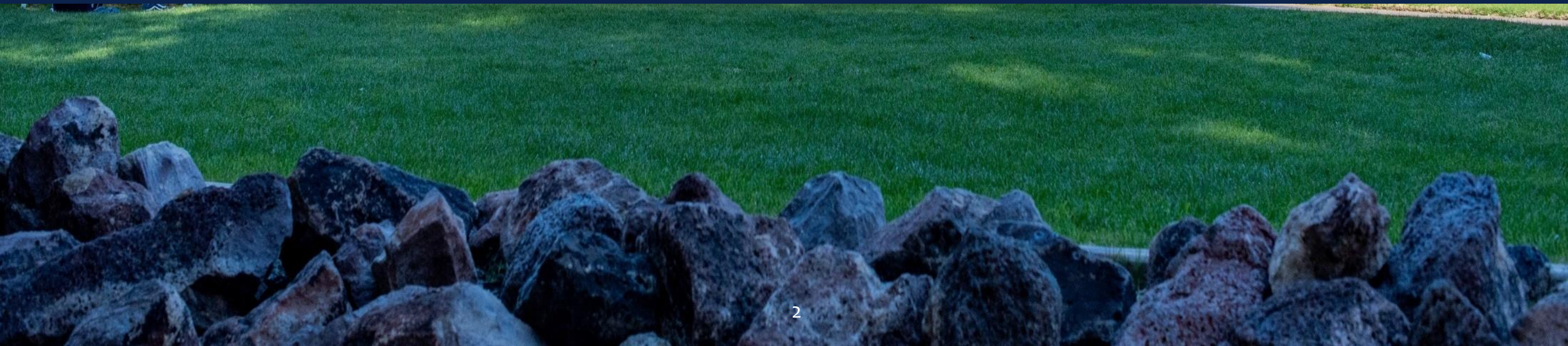
Food, Energy and Water (FEWS) Learning Modules

June 2021



Electrical Systems and System Sizing

Presented by Anna Rich



Sizing a System

Factors that impact a grid tied system

* Budget
* Available area for system
* Annual energy consumption

Factors that impact a stand-alone system

* Annual energy consumption
* Available solar resource

Sizing a System: Peak Sun Hours

Peak Sun Hours (PSH): The number of hours the PV system is expected to operate at rated standard test conditions.

* PSH is specific to region
* Depends on tracking abilities, panel tilt and orientation.

Sizing a System: Peak Sun Hours

Calculating annual energy generation from PSH

PSH for area: Divide daily insolation value for geographic area by 1000 W/m[2] (Standard Test Condition (STC) irradiance level).

Example:

$$PSH_{Arizona} = 6.5 \frac{\frac{kWh}{m^2}}{day} \div \frac{1kW}{m^2} = 6.5 \frac{hours}{days}$$

For a 2kW system,

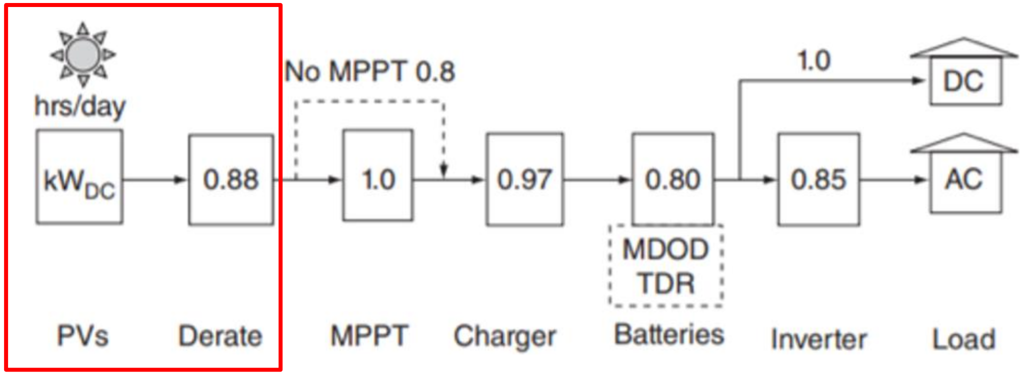
$$Annual\ energy\ yield = 2kW \times 6.5 \frac{hours}{day} \times 365 \frac{days}{year} = 4745 \frac{kWh}{year}$$

Sizing a System: Derate Factor

PV array efficiency is affected by age and degradation, operating temperature, soiling or shading, and losses in wiring.

Derate Factor takes this into account.

* Specific to PV array
* Acceptable range: 0.75 - 0.95 (5% to 25% total losses)



Sizing a System: Estimating Demand Example

Example 6.9 A Modest Household Demand. Estimate the monthly energy demand for a cabin with all AC appliances, consisting of a 19 cu ft refrigerator, six 25-W compact fluorescent lamps (CFLs) used 6 h/d, a 44-in LCD TV turned on 3 h/d and connected to a satellite with digital video recording (DVR), 10 small electric devices using 3 W continuously, a microwave used 12 min/d and a small range burner 1 h/d, a clothes washer that does four loads a week with solar heated water, a laptop computer used 2 h/d, and a 300-ft deep well that supplies 120 gal of water per day.

Sizing a System: Estimating Demand Example

TABLE 6.11 Power Requirements of Typical Household Loads

Kitchen Appliances	
Refrigerator/freezer: Energy Star 14 cu ft.	300 W, 950 Wh/d
Refrigerator/freezer: Energy Star 19 cu ft.	300 W, 1080 Wh/d
Refrigerator/freezer: Energy Star 22 cu ft.	300 W, 1150 Wh/d
Chest freezer: Energy Star 22 cu ft.	300 W, 1300 Wh/d
Dishwasher (hot dry)	1400 W, 1.5 kWh/load
Electric range burner (small/large)	1200 / 2000 W
Toaster oven	750 W
Microwave oven	1200 W
General Household	
Clothes dryer (gas/electric, 1400 W)	250 W; 0.3 / 3 kWh/load
Washer (w/o H_2O heating/with electric heating)	250 W; 0.3 / 2.5 kWh/load
Furnace fan: $^1/_2$ hp	875 W
Celling fan	100 W
Air conditioner: window, 10,000 Btu	1200 W
Heater (portable)	1200–1875 W
Compact fluorescent lamp (100 W equivalent)	25 W
Clothes iron	1100 W
Clocks, cordless phones, answering machines	3 W
Hair dryer	1500 W

Consumer electronics (Active/Standby)	
TV: 30–36 in Tube	120 / 3.5 W
TV: 40–49 in Plasma	400 / 2 W
TV: 40–49 in LCD	200 / 2 W
Satellite or cable with DVR (Tivo)	44 / 43 W
Digital cable box (no DVR)	24 / 18 W
DVD, VCR	15 / 5 W
Game console (X-Box)	150 / 1 W
Stereo	50 / 3 W
Modem DSL	5 / 1 W
Printer inkjet	9 / 5 W
Printer laser	130 / 2 W
Tuner AM/FM	10 / 1 W
Computer: Desktop (on/sleep/off)	74 / 21 / 3 W
Computer: Notebook (in use/sleep)	30 / 16 W
Computer monitor LCD	40 / 2 W
Outside	
Power tools, cordless	30 W
Circular saw, 7 1/4 in	900 W
Table saw, 10 in	1800 W
Centrifugal water pump: 50 ft at 10 gal/min	450 W
Submersible water pump: 300 ft at 1.5 gal/min	180 W

Sizing a System: Estimating Demand Example

Solution. Using data from Table 6.11, we can put together the following table of power and energy demands. The total is about 6.3 kWh/d which is about 2300 kWh/yr.

Note:

1)Kitchen uses 40% of total due to all-electric stove.

2)An efficient refrigerator is being used which is important in a PV system

Appliance	Power (W)	Hours/day	Wh/d	Percentage
Refrigerator, 19 cu ft	300		1080	17%
Range burner (small)	1200	1	1200	19%
Microwave at 12 min/d	1200	0.2	240	4%
Lights (6 at 25 W, 6 h/d)	150	6	900	14%
Clothes washer (4 load/wk at 0.3 kWh)	250		171	3%
LCD TV 3 h/d (on)	200	3	600	10%
LCD TV 21 h/d (standby)	2	21	42	1%
Satellite with DVR	44	3	132	2%
Satellite (standby)	43	21	903	14%
Laptop computer (2 h/d at 30 W)	30	2	60	1%
Assorted electronics (10 at 3 W)	30	24	720	11%
Well pump (120 gal/d at 1.5 gal/min)	180	1.33	240	4%
Total	3566		6288	

Sizing a System: Sizing Example

Example: How would you size a PV system to satisfy a 6.3 kWh/d demand in Tucson, AZ? Assuming Tucson gets 5.5 full sun hours per day (at 1000W/m^2) in the winter, and a 0.8 derate factor.

$$P_{DC}(kW) = \frac{Energy\ (kWh/d)}{(h/d\ full\ sun)(Derate)}$$

Solution: We want to meet a 6.3kWh/d demand.

$$P_{DC}(kW) = \frac{6.3\ kWh/d}{(5.5\ h/d)(0.8)} = \boxed{1.43kW}$$

Sizing a System: Sizing Example

Example: How many solar panels in series would you need to power this demand? Assume maximum power P_{max} = 300W

Solution: We want to meet a 1.43kW demand.

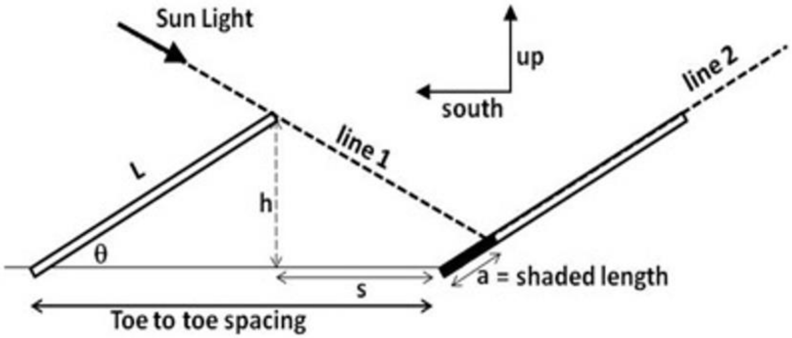
$$\textbf{Number of Panels} = \frac{1.43\text{kW}}{300\text{W}} = 4.76 = 5 \text{ panels}$$

Sizing Considerations

* PV panel efficiency – usually between 18% - 25%
* Inverter efficiency – usually between 85% - 95%
* Number of panels used in system – area available for PV use
* Panel configuration – series and parallel connections
* Battery storage capacity – want the PV system to be able to charge batteries while supporting the electric load
* Derate factor – how much the power production can be expected to change based on panel temperature

Shading

Shading is a very big problem in installing solar panels and arrays. Even the shading of a single row can shut down an entire module.



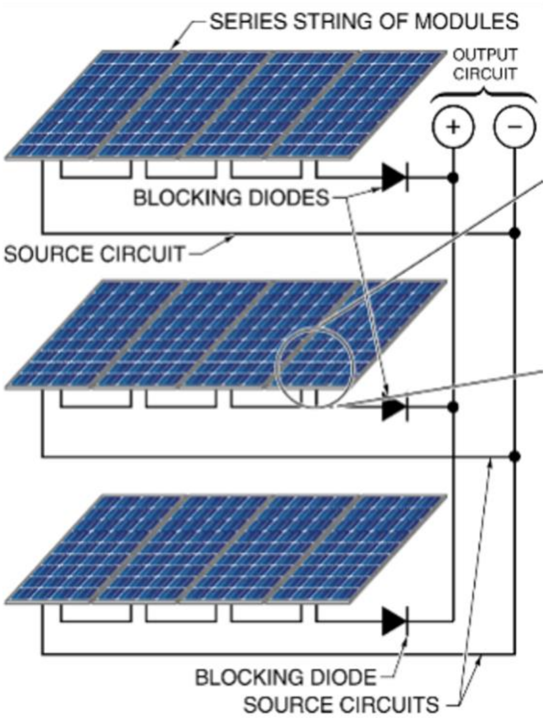
Recommended toe-to-back spacing, s = 3h
PV array fields generally do not follow this recommendation because of high land costs.

Effect of Shading

- If a solar cell is shaded, it will not generate a voltage.
- In a series configuration, it just acts as resistor and reduces the voltage of the entire row.
- Parallel rows will generate more voltage and will drive current backwards into the row with the shaded cell.
- The shaded solar cell will heat up.

Bypass and Blocking Diodes

- If shading or cell failure occurs, then the adjacent cells and rows will dump current into the shaded cell or group of cells.
- This can heat the cell and cause premature failure or can lower the cell voltage which turns off the inverter.
- Increased temperature also reduces the efficiency and the power produced by PV.



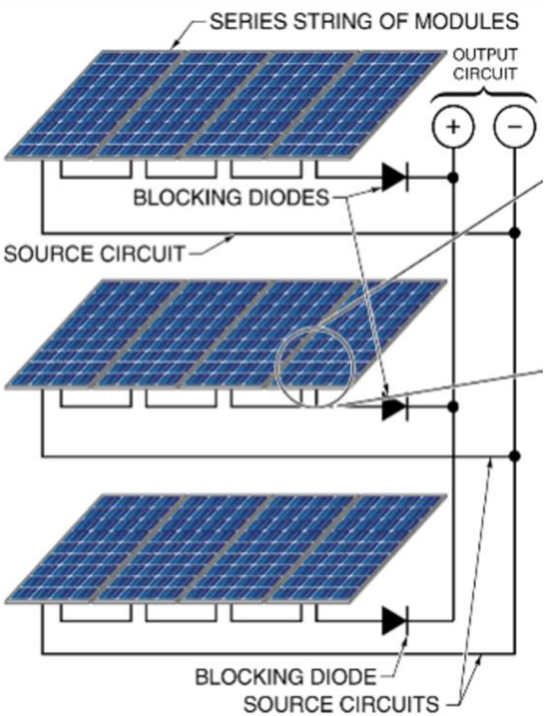
BLOCKING DIODES

J. R. Dunlop, Photovoltaic Systems, American Tech. Pub, 2010

Bypass and Blocking Diodes

Solutions:

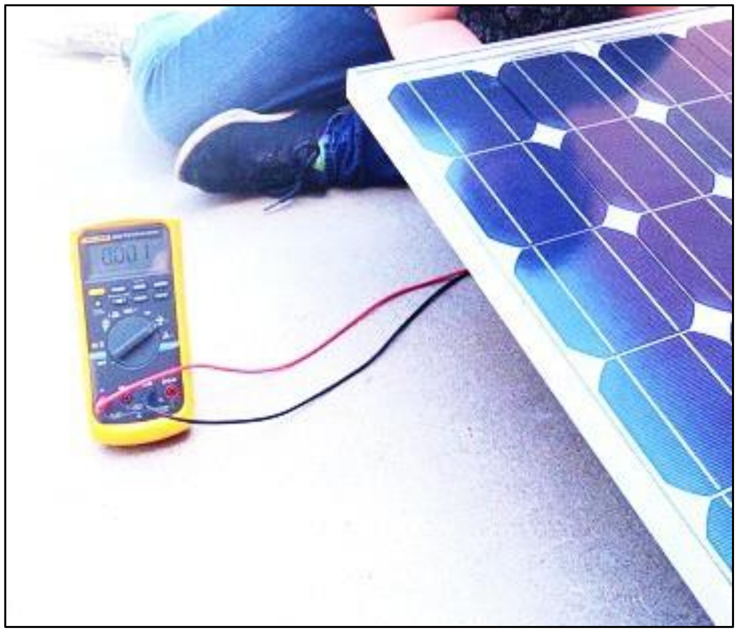
- Blocking diodes are used between panels to stop reverse current from flowing into the shaded panel.
- Bypass diodes are used between cells to guide the current around the shaded cell.
- These diodes are either built in the internal module circuitry or added in the junction box.



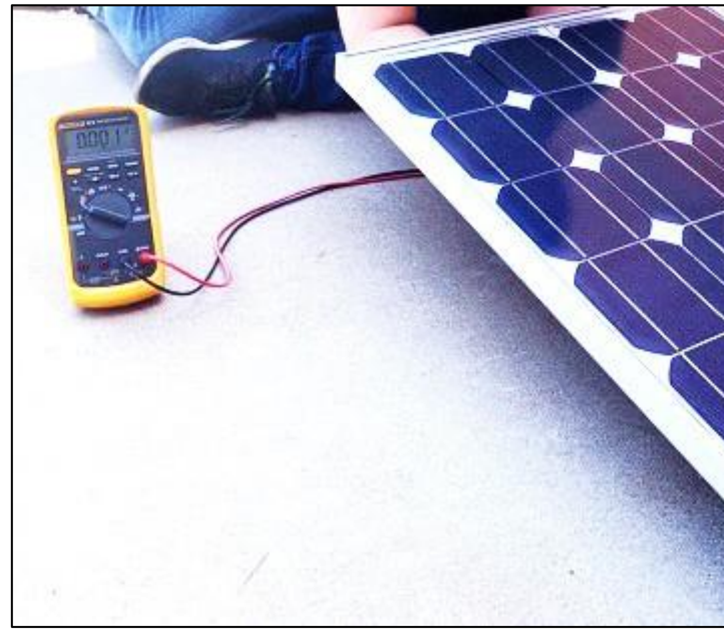
BLOCKING DIODES

J. R. Dunlop, Photovoltaic Systems, American Tech. Pub, 2010

PV Shading Demonstration
Shaded PV Panel

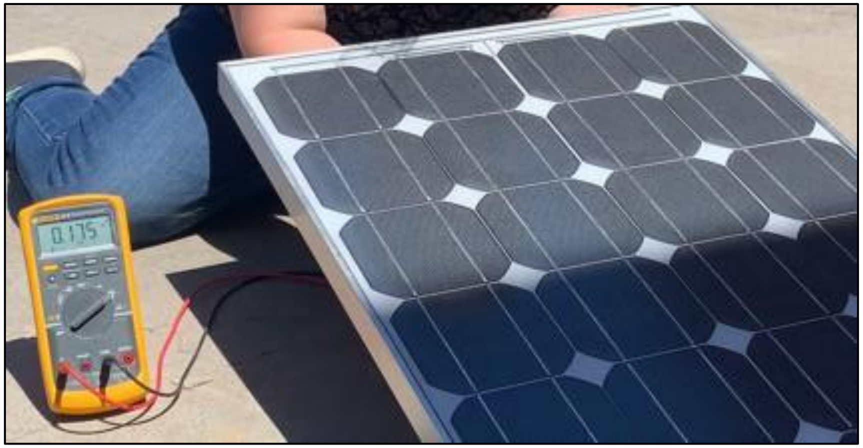


Current measurement of a completely shaded PV panel reading 0.001 A



Voltage measurement of a completely shaded PV panel reading 0.001 V

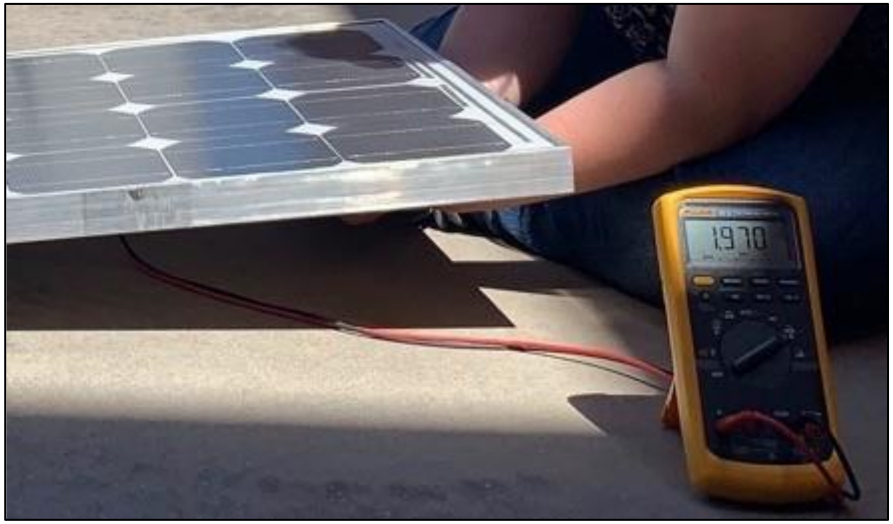
PV Shading Demonstration Partially-Shaded PV Panel



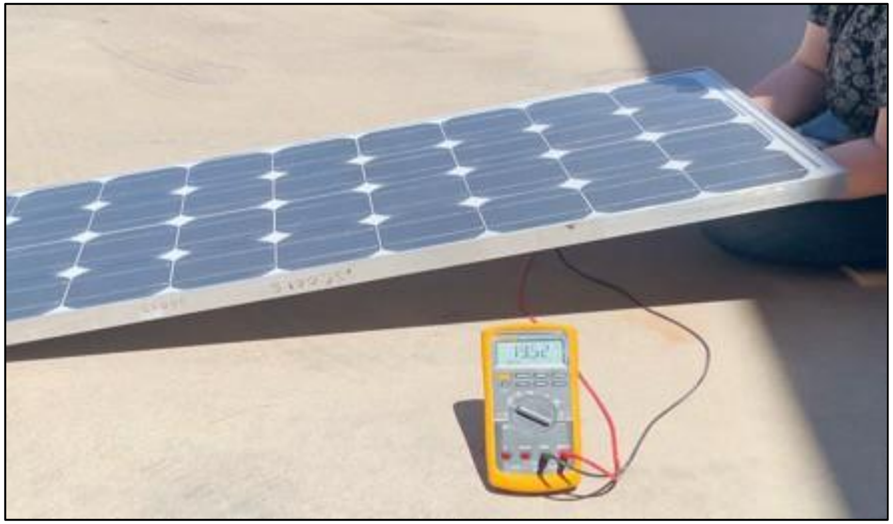
Current measurement of a partially-shaded PV panel reading 0.175 A

Voltage measurement of a partially-shaded PV panel reading 15.64 V

PV Shading Demonstration Illuminated PV Panel



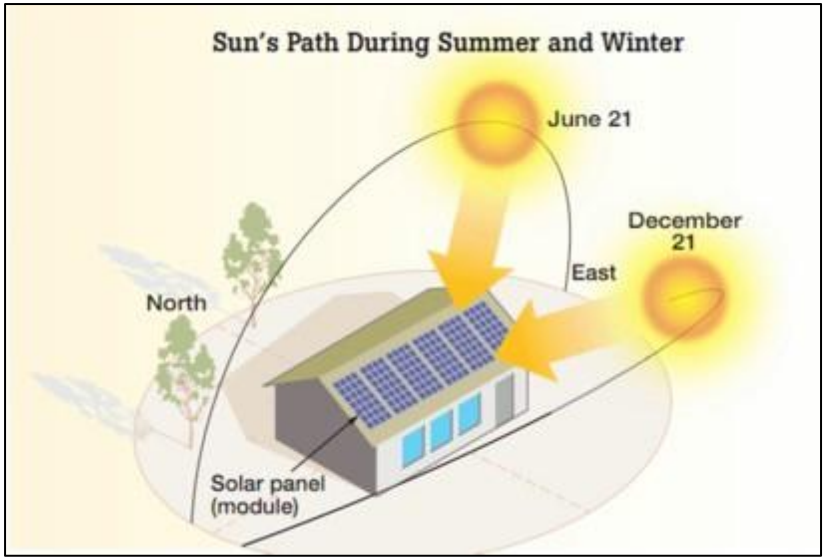
Current measurement of a completely illuminated PV panel reading 1.97 A



Voltage measurement of a completely illuminated PV panel reading 19.52 V

PV Panel Angle

* Solar panels in the northern hemisphere should be mounted facing south
* Stationary panels should be mounted at an angle equal to the latitude of their location for maximum average power production
* Panel power output will change over the course of the day and year based on the movements of the sun



https://medium.com/@solarify/which-direction-must-solar-panels-face-and-what-angle-should-they-be-tilted-at-7242c671e4b9

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9 Dunlop, J. R. (2010). *Photovoltaic Systems*, American Tech.

10 “*Which direction must solar panels face, and what angle should they be tilted at?*”, Solarify on Medium, 2-Aug-2018. [Online]. Available: https://medium.com/@solarify/which-direction-must-solar-panels-face-and-what-angle-should-they-be-tilted-at-7242c671e4b9

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