Tuesday, 11/2/23

Sizing a Stand-Alone PV Systems

Two questions to consider:

(1) What size PV array do I need?

(2) What size battery bank do I need?

Consider a metric for answering these questions:

How serious is a loss of power?

(1) PV in Space

Loss of power is very serious.

PV in space is very reliable:

→ No weather effects,

→ Constant, predictable insolation (when in sunlight).

(2) PV Powered Refrigeration

Could be a rural hospital in the 3rd world that is storing medicine.

The risk there would be expense and possible loss of life.

(3) PV Powered Signs, Emergency Phones, Railroad Crossings, Etc.

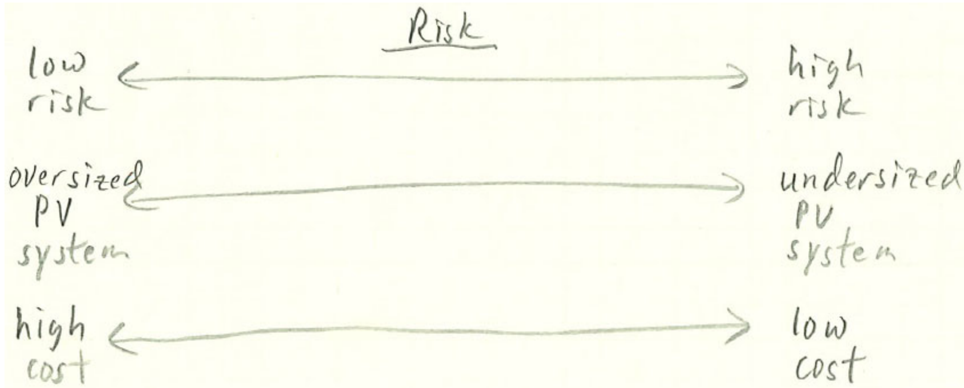
The risk ranges from minimal to possible loss of life.

(4) PV Powered Residence, Hunting Cabin, Ski Chalet, Etc.

The risk here is usually just inconvenience.

1) Evaluating Risk of Loss of Power

Consider where the application falls on the chart below:



From this chart, you can determine how to proceed.

a. Determining PV Power Needs

(1) Select which electric appliances will be powered off of PV.

Note: traditional high power electric appliances are usually not powered off of PV:

Water heater

Space heater / heat pump

Air conditioner

Stove / oven

Clothes Dryer

Therefore, select energy efficient, low-power appliances and devices.

(2) Determine how many of each appliance and how many hours per day it will be used.

(3) Determine the estimated energy needed per day (Wh/day)

Consider Fig. 5.15 for calculating a 2.2 kWh/day estimated energy usage need.

Appliance	Power (W)	No.	Average hrs/day	Average Wh/day
Light	11	8	3	260
TV	60	1	4	240
Computer	60	1	3	180
Refrigerator	80	1	24 (on-off)	500
Kettle	1000	1	0.2	200
Microwave Oven	700	1	0.4	280
Food Mixer	400	1	0.15	60
Washing Machine	800	1	0.6	480
			Total	2200

Figure 5.15 Appliances and energy requirements for a stand-alone system.

(4) Determine the needed size of the PV array and the battery bank.

Define "Peak Sun Hours" as the equivalent number of daily hours at 1 kW/m^2 insolation.

Example: if an inclined PV array receives 3 kWh/m^2 per day in April (on average).

This corresponds to 3 peak sun hours.

Find and examine the daily solar radiation data for your location.

Consider Fig. 5.16 as an example:

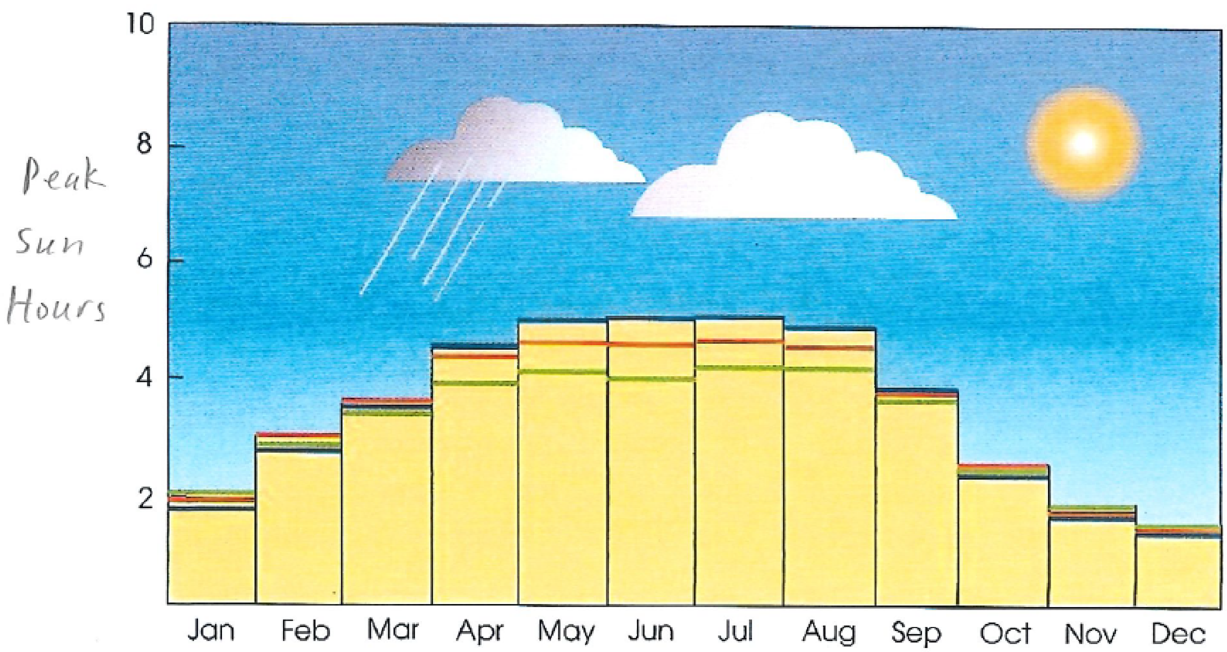


Figure 5.16 Daily solar radiation in kWh/m^2 on south-facing inclined PV arrays for a location at latitude 48 °N in southern Germany. Three values of array tilt are illustrated: 33° (blue); 48° (red); and 63° (green).

Observe from Fig. 5.16 that the inclination angle affects peak sun hours over the year.

Decide which time of year the risk of power loss is most critical:

Summer vacation cabin?

Winter ski chalet?

Fall hunting cabin?

Year-round residence?

b. Sizing the PV Array

Unless you have lots of money, you want to avoid oversizing your PV system.

Defining some terms:

E_D ≡ average daily amount of electricity needed

P_{PV} ≡ rated peak power of the PV array

S_P ≡ number of peak sun hours per day in the month of interest

η ≡ overall system efficiency (after the PV modules)

Solve for P_{PV}:

$$P_{PV} = \frac{E_D}{S_P \eta}$$

For typical values: E_D = 2.2 kWh/day, S_P = 3.5 h (March), η = 60%:

$$P_{PV} = \frac{2.2}{(3.5)(0.6)} = 1.05\ kW_P$$ → useful March to September.

A typical value for PV system efficiency is about 60%. This value is a product of:

PV module without MPPT: 85%*

Battery bank: 85%

Charge controller, blocking diodes, cables: 92%

Inverter: 90%

* Note: the 85% PV module efficiency means that 85% of the module's rated output power actually comes out of the module.

If a PV module has MPPT: η approaches 70%, but the initial cost is higher.

Therefore, you would typically oversize the PV array by about 20%

For the system with P_{PV} = 1.05 kW_P, use a 1.2 kW_P PV array.

c. Sizing the Battery Bank

Typically, you would size the battery bank for 5 days of use.

Here: $E = (5)(2.2\ kWh) = 11\ kWh$.

However, if the application is life dependent, size the battery bank for 15 days or longer.

Defining some terms:

C ≡ battery bank capacity

N ≡ number of days of battery storage

E_D ≡ daily electrical requirement

D ≡ allowable battery depth-of-charge

η_{inv} ≡ inverter efficiency <if AC is required>

Example: 5 days, 80% maximum battery discharge, 90% inverter efficiency:

$$C = \frac{NE_D}{D\eta_{inv}} = \frac{(5)(2.2)}{(0.8)(0.9)} = 15.3\ kWh$$

If as 24 V battery bank is used → 638 Ah battery capacity needed.

Similar to the PV module, slightly oversize the battery bank.

Therefore, the total PV system is:

Eight 150 W_P PV modules (1.2 KW_P total)

Eight 12 V 175 Ah batteries (16.8 kWh total)

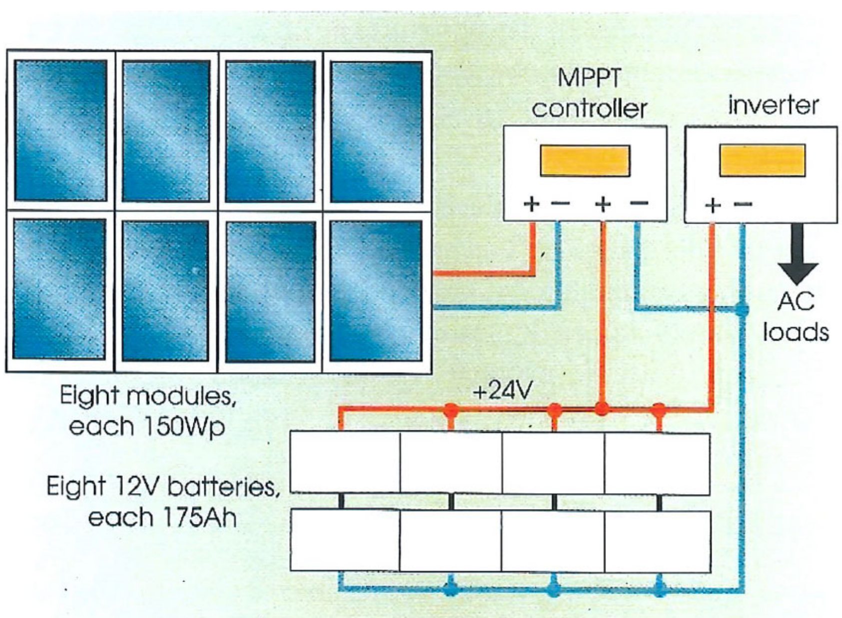


Figure 5.17 A suitable system for the holiday home.

Space Stand-Alone Applications

Space was the first significant PV market.

> ~ 50 years ago, PV was so expensive that few other applications could afford it.

a. Special Features of Space Environments

Space radiation levels can damage PV cells.

Sunlight in space has a different spectrum than on Earth:

> Earth's atmosphere filters sunlight going through it.
>
> In space, use AM0: "Air Mass Zero."

Space platforms often experience dramatic changes in temperature and sunlight intensity from moving in and out of shadow.

> This induces high thermal stresses in PV cells and modules.

Size and weight are very expensive to launch into space.

> Desire to keep the PV system as small as possible.

Sustained performance is paramount, especially for long space missions.

b. Variety in Space Environments.

(1) Temperature extremes

> Low earth orbit: -80ºC in shadow.
>
> Jupiter's orbit: -125ºC (even in sunshine!).
>
> Mars orbit: +145ºC in sunlight.

(2) Sunlight intensity

> At Mercury: approximately double the sunlight intensity at Earth.
>
> At Jupiter: approximately 1/13 the sunlight intensity at Earth.

(3) Radiation can be particularly high:

Mid–Earth orbits (MEOs): passes through the Van Allen radiation belts.

Near Jupiter.

During high solar activity (solar flares, etc.).

(4) Atmospheric chemistries/properties on other planets

Mars: dust, possibly corrosive atmosphere.

Venus: very hot (~450ºC), very corrosive / high pressure atmosphere, thick cloud cover.

c. Space Application PV Technology

Tipple-junction cells based on GaAs technology are used:

Up to 30% efficiency in AM0.

International Space System (ISS):

Uses 262,400 Si PV cells

84 to 120 kW can be produced by the cells

~2500 m^2 of PV cells

Rechargeable batteries (four 110 Ah battery assemblies)

Each battery assembly:

ISS used to use 48 nickel-hydrogen batteries.

As of 2021, NASA finished replacing the batteries with 24 Li-ion batteries (~10 year rated service life).

The battery assemblies provide continuous power to ISS during the "eclipse" portion of each orbit (35 min of each 90 min orbit)