Off-Grid Solar Systems

for Radio Sites

Presented by Marcel Stieber, AI6MS

Presented to the Cal Poly Amateur Radio Club, W6BHZ

Virtual Meeting via Zoom on Thursday, April 9th, 2020

Who is this guy?

- Marcel Stieber, AI6MS
- Licensed in 2008 as KI6QDJ
- Cal Poly Electrical Engineering 4+1

- CPARC Industry Advisor
- Cupertino ARES Repeater Trustee
- All Out Events Comms Director
- Salinas Valley Repeater Group

- Playing with solar since ~~1995~~ 2010
- Currently have 2 off-grid radio sites
  - One running non-stop since 2016

*Slides and video available at www.qrz.com/db/ai6ms

Abstract

This presentation will walk through the system design for off-grid solar-powered radio sites including power budgets, equipment selection, and maintenance. We'll use a case study to explore specific design details and decisions to help you deploy your first fully-off-grid solar-powered radio site!

This is a bi-directional QSO...

So ask questions!

*Slides and video available at www.qrz.com/db/ai6ms

A brief show of hands

Forum Overview

- Intro to Solar Systems
- DC Loads
- Battery
- Solar Panels
- Solar Controller
- Deployment!
- Maintenance

*Slides and video available at www.qrz.com/db/ai6ms

Photo from WB6ECE

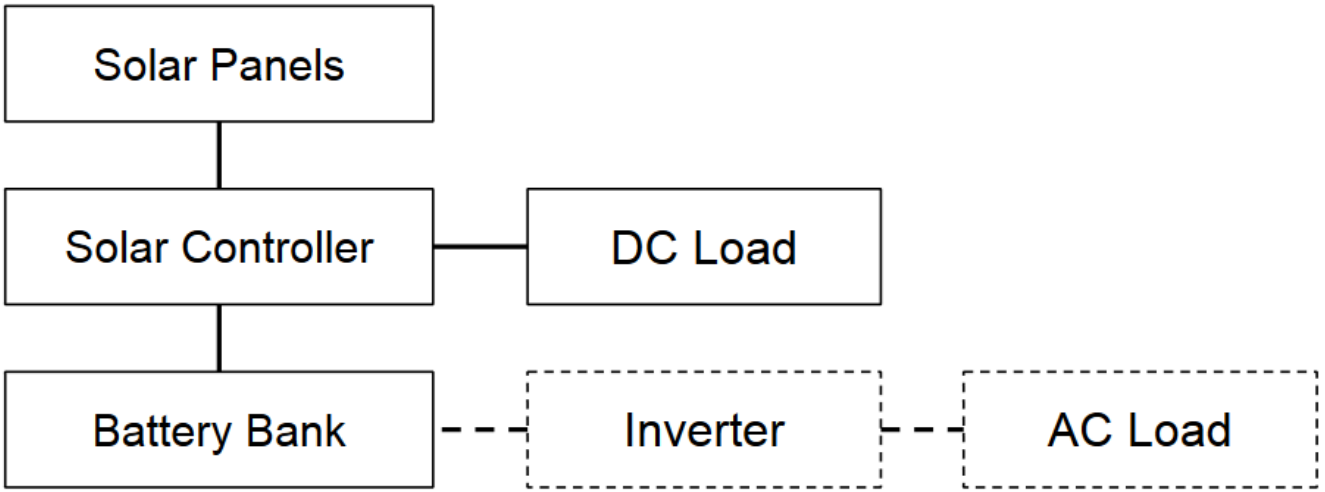
Intro to Solar Systems

Why solar?

- You need power for your radios!
- Getting grid power is expensive
- Off-Grid gives you independence
- Low-operating costs

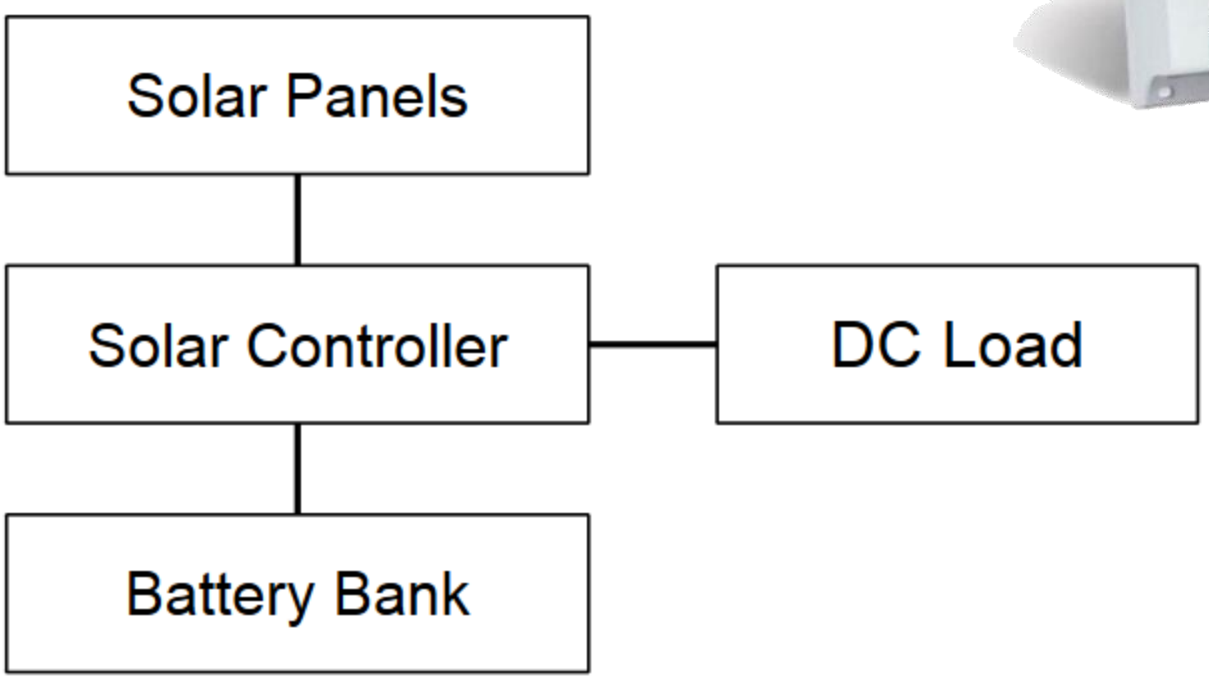
Residential vs Radio Site

- Residential
  - Usually requires an inverter for AC loads
    - Microwaves, fridges, TVs, etc.
- Radio sites
  - Everything can run DC!?



Assumptions

- Off-Grid (no AC power)
- DC Loads only (no inverters)
- Design using off-the-shelf solutions



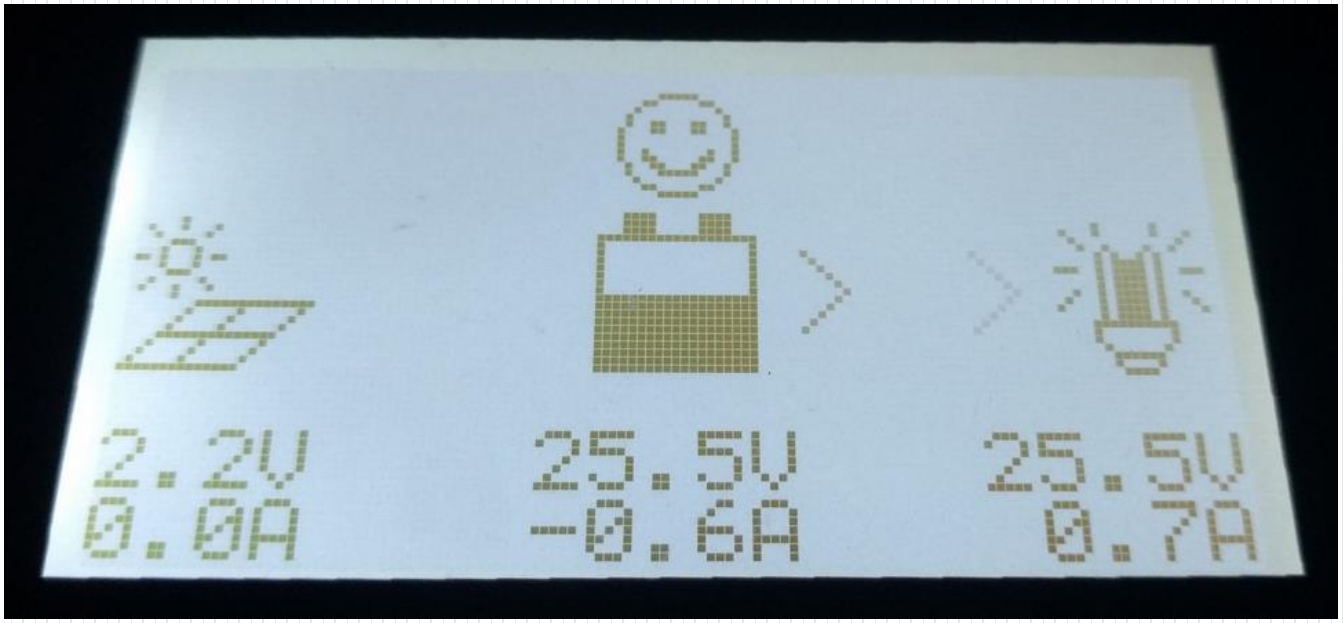
Mental Model

- Off-Grid Systems are designed for the WORST CASE
  - Shortest days of sunlight (winter)
  - Coldest temperatures
  - Cloudiest days
  - Maximum system loads
- Goal is to get to 100% Up-Time!

Our **Case Study**

- Cupertino ARES ARKnet Project
- Wireless Intranet Client Site
- Equipment supported
  - Uplink Radio
  - Wireless Access Point
  - Webcam
  - Analog Telephone Adapter

DC Loads



What are you doing with this?

- Weather Station
- Repeater Site
- APRS Digipeater
- Mesh Network Node
- Remote Base

How much power do you need?

- Need total **Watt-Hours Per Day** of usage
- Some rough examples:
  - 50 watt repeater site 100% duty cycle
    - Ex: Yaesu DR2X (13A on TX) = ~150 watts DC
    - 24hrs/day = **5760 watt-hours/day**
  - 50 watt repeater site 10% duty cycle
    - ~20 watts RX
    - (20W x 90% + 150W x 10%) x 24hrs = **792 watt-hours/day**
  - 10 watt digipeater
    - @100% duty cycle = **240 watt-hours/day**

Case Study: Online load calculator!

- https://www.altestore.com/store/calculators/load_calculator/
- Be sure to include *everything* at the site!

Appliance/Load Name	On at Same Time*	Quantity	AC Watts	AC Surge*	DC Watts*	Hours On per Day	Watt-Hours / Day
Uplink Radio	☑	1	0		12	24	288
Wireless Access Point	☑	1	0		8	24	192
Webcam	☑	1	0		3.75	24	90
Analog Telephone Adap	☑	1	0		6	24	144
Ethernet Switch	☑	1	0		7.5	24	180

Add load

Total Watt-Hours/Day: 894

*Values only needed if you want a system which operates with batteries (e.g. an off-grid solar system)

Batteries!

Batteries

- Typically:
  - Deep-Cycle Lead-Acid
    - but LiFePO4 can be more cost-effective
  - 12 Volts (plus series/parallel configurations)
  - 35-200Ah Capacity per battery
  - Low-cost per Ah for Lead-Acid
    - 3-4 times the price for LiFePO4, but you get the full rated capacity

Universal UB121000-45978 12v 100AH Deep Cycle AGM Battery
by Universal Power Group
$144.93 + $15.01 shipping

Battle Born LiFePO4 Deep Cycle Battery - 100Ah 12v with Built-in BMS - 3000-5000 Deep Cycle Rechargeable Battery - Perfect for RV/Camper, Marine, Overland/Van, and Off Grid Applications
4.5 ★★★★½ 119
$949.00
FREE Shipping

Battery Bank Sizing

- Start with the Daily Energy Usage
- Then apply Derating:
  - Days without sun or reduced sun
    - How many days of backup power do you need?
    - Cloudy days produce only 20-40% solar output
  - Battery temperature
    - Colder temps are worse
  - Depth of Discharge
    - Less is more!
- Typically use 3 days to 50% DOD
  - For lead-acid…for LiFePO4, up to 100% DOD

Case Study: Battery Sizing

- 894 watt-hours/day
- 3 backup days
- Temperature derating for 30°F = 1.40
- 50% depth of discharge for lead acid

- (894Whr/day) * (3 days) * 1.40 / (50%) ≈ 7510Wh

- Then divide by the battery system voltage (24V) to get the minimum Amp-hour Capacity of your battery bank

- 7510Whr/24V ≈ 313Ah for lead acid

Battery Bank Sizing

This calculator will help you size the battery bank for your system.

STEP 1:

Your Daily Energy Usage

Watt Hours per Day: 894

STEP 2:

How Many Days Should Your System Run without Sun?

3

STEP 3:

Adjust the Effective Capacity of Your Battery Bank Due to Low Temperatures

What is the lowest temperature your battery bank will experience?

30F (-1C) Degrees

RESULTS:

Battery Bank Capacity: **8637 watt hours**

Select a battery bank voltage 24

Battery Bank Capacity: **360 amp hours**
3 String Configuration: **120 amp hours** per string

- https://www.altestore.com/store/calculators/off_grid_calculator/

Case Study: What's this look like?

- Our "little" ARKnet radio site would need:
  - ~4 x 200Ah 12V lead-acid batteries
  - Or 8 x 100Ah 12V lead-acid batteries

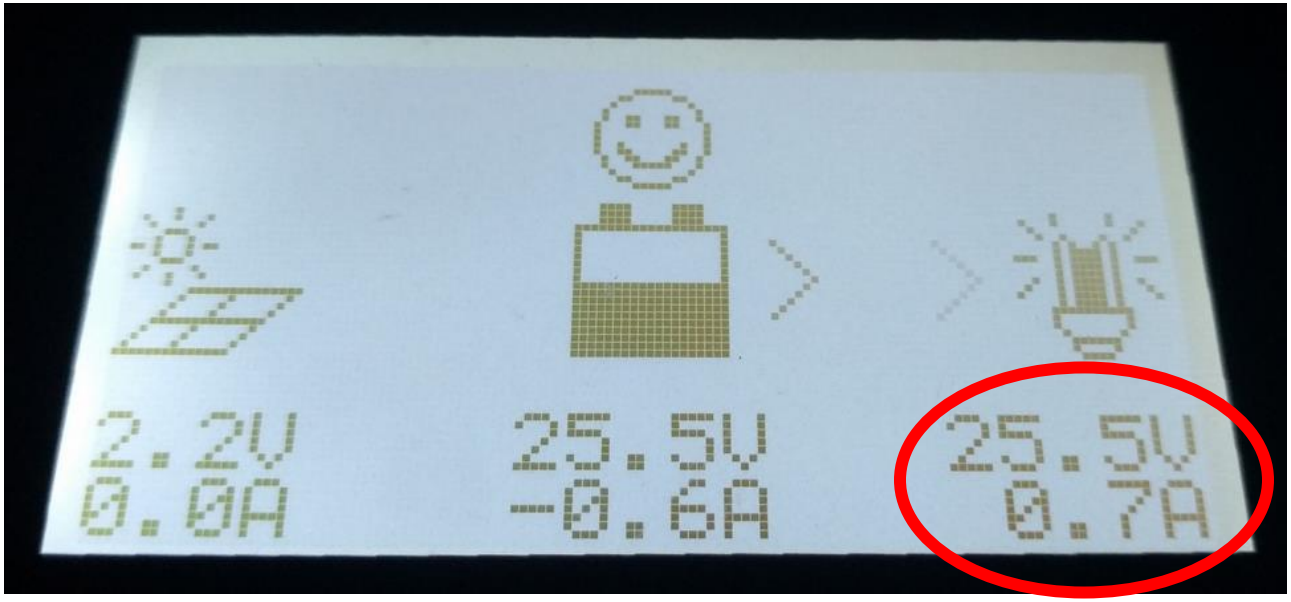
Renogy Deep Cycle Pure Gel Battery 12V 200Ah
by Renogy
$438.92 prime

Sponsored
NPP NP6-200Ah 6V 200Ah AGM Deep Cycle
by NPP
$209.99

2pcs WindyNation 100 amp-hour 100AH 12V 12 Volt AGM Deep Cycle 100 amp-hour)
by WindyNation
$413.99 prime
FREE Delivery by **Wed, Oct 17**

Case Study: What do you *actually* need?

- Critical to get your load calculations right!
- Lots of factors come into play:
  - Actual duty cycle
  - Actual measurements vs datasheet
  - Expected usage and worst-case planning



Only 18 Watts!

(vs 37 watts)

Battery Bank Sizing

This calculator will help you size the battery bank for your system.

STEP 1:

Your Daily Energy Usage

Watt Hours per Day: 450

STEP 2:

How Many Days Should Your System Run without Sun?

2

STEP 3:

Adjust the Effective Capacity of Your Battery Bank Due to Low Temperatures

What is the lowest temperature your battery bank will experience?

30F (-1C) Degrees

RESULTS:

Battery Bank Capacity: **2691 watt hours**

113Ah vs 360Ah!

Select a battery bank voltage 24

Battery Bank Capacity: **113 amp hours**
3 String Configuration: **38 amp hours** per string

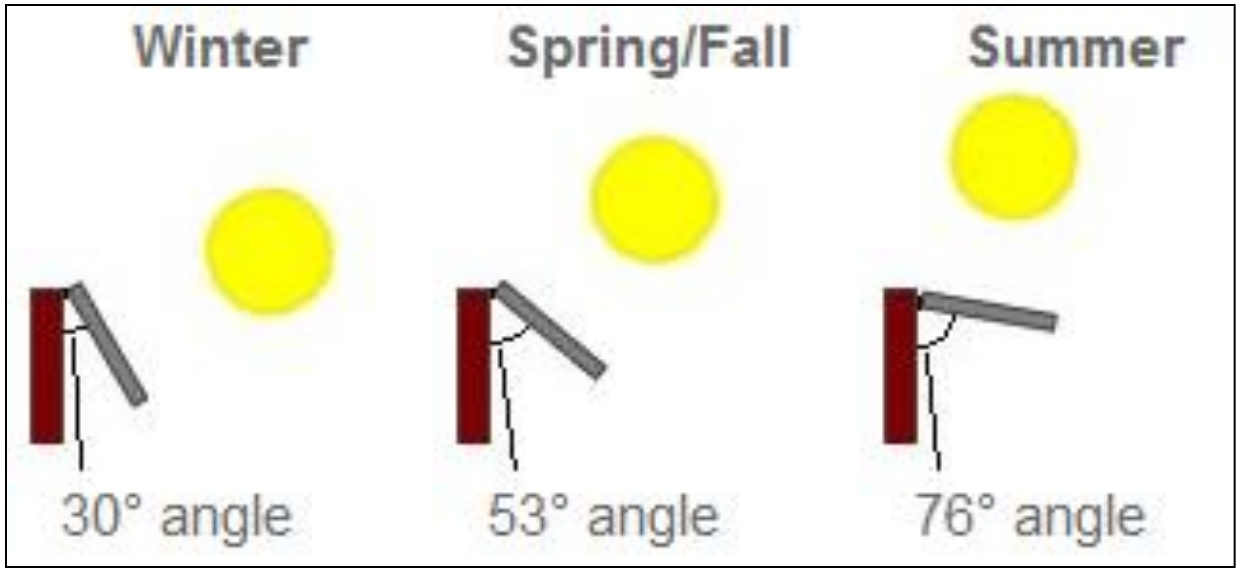
- https://www.altestore.com/store/calculators/off_grid_calculator/

Case Study: 100Ah @ 24V

Solar Panel

Solar Panel Mental Model

- Grid-Tied – Maximize Annual Production
- Off-Grid – Max power on the shortest day
  - Use the shortest day of the year
  - In the northern hemisphere, point due south
  - Match the angle of the sun in the winter



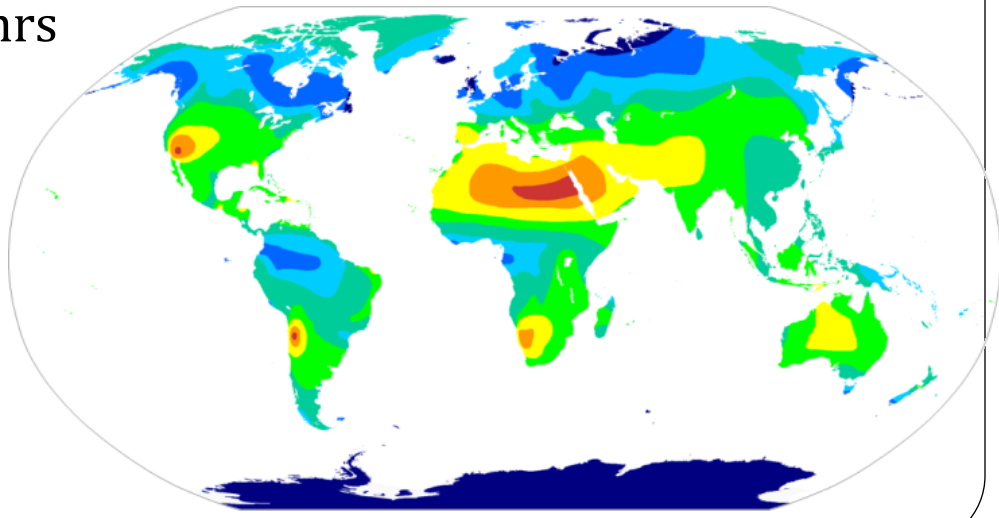
Solar Panel Sizing

- How much power?
  - Our previous watt-hours/day
    - 450 Whr/day
- How much sun?
  - Peak Sunlight Hours

Peak Sunlight Hours

- Hours where sunlight is >1000 watts per sq. meter
- 7 hrs of daylight may only be 3-4 peak sun-hours

- Insolation map
  - Average peak sun-hours for the shortest day*
    - *aka the darkest time of year (winter solstice)
  - Examples**:
    - San Francisco, CA - 3.4 hrs
    - New York, NY - 2.8 hrs
    - Seattle, WA - 1.4 hrs
    - Tucson, AZ - 5.1 hrs
    - Fairbanks, AK - 0.3 hrs



**Numbers vary by source…

Case Study: Solar Panel Sizing

- Daily Energy Usage / Peak Sunlight Hours
  - 450 Whr/day / 3.4 hrs = 132 W/day
- This would be:
  - 2 x 100W solar panels
  - 1 x 200W solar panel (more headroom!)

See Size Options

HQST 100 Watt 12 Volt Polycrystalline Solar Panel
by HQST
$102.99 ~~$139.99~~

ALTE 200 WATT 24V POLY SOLAR PANEL

$189.00

Case Study: Solar Panel Specs

- Renogy 250 Watt Polycrystalline Solar Panel
- Maximum Power: 250W
- Open-Circuit Voltage (Voc): 37.30V
- Short-Circuit Current (Isc): 8.84A

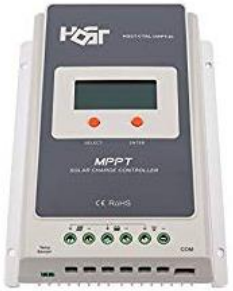
Solar Controller

Solar Controller Types

- PWM (Pulse Width Modulated)
  - Pros: Small and cheap
  - Cons: lower efficiency, tighter matching required

HQST 30 Amp PWM Smart Solar Charge Controller
by HQST
$28.99 prime | FREE One-Day

- MPPT (Maximum Power Point Tracking)
  - Pros: highest efficiency, very compatible
  - Cons: expensive



HQST 30A MPPT Solar Charge Controller
by HQST
$101.99 prime

Solar Controller Sizing

- Key Factors:
  - Total Solar Panel Wattage
  - Battery Voltage
  - DC Load Peak Current
  - Max Input Voltage (Solar Panel Open-Circuit Voltage)

20A Commander MPPT Controller	
Nominal system voltage	12V/24V Auto Recognition
Max. PV Input Short Current	25A
Battery Voltage Range	8V -32V
Max. Solar Input Power	12V@260W | 24V@520W
Self -Consumption	1.4W to 2.6W

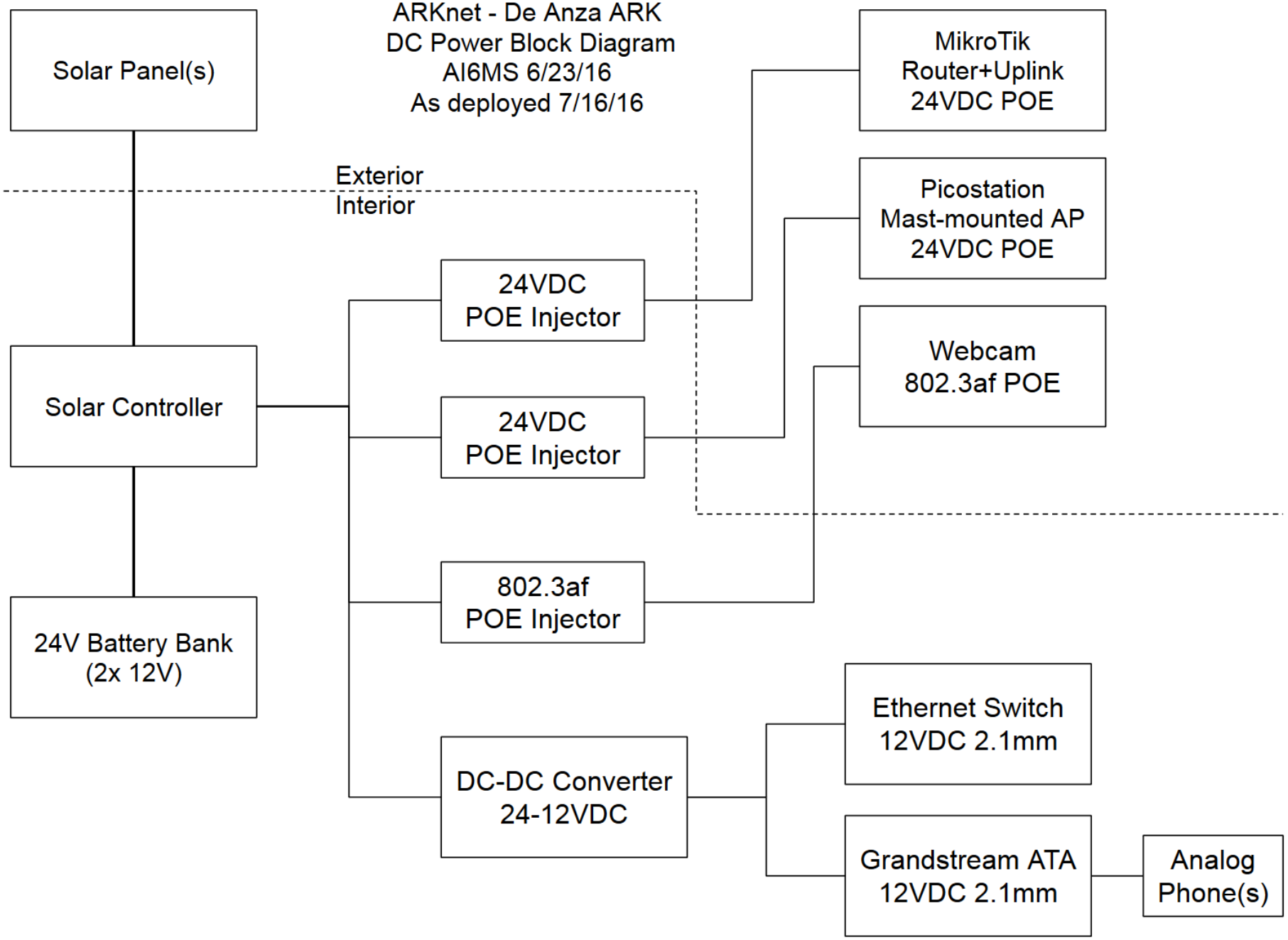
Case Study: Controller Sizing

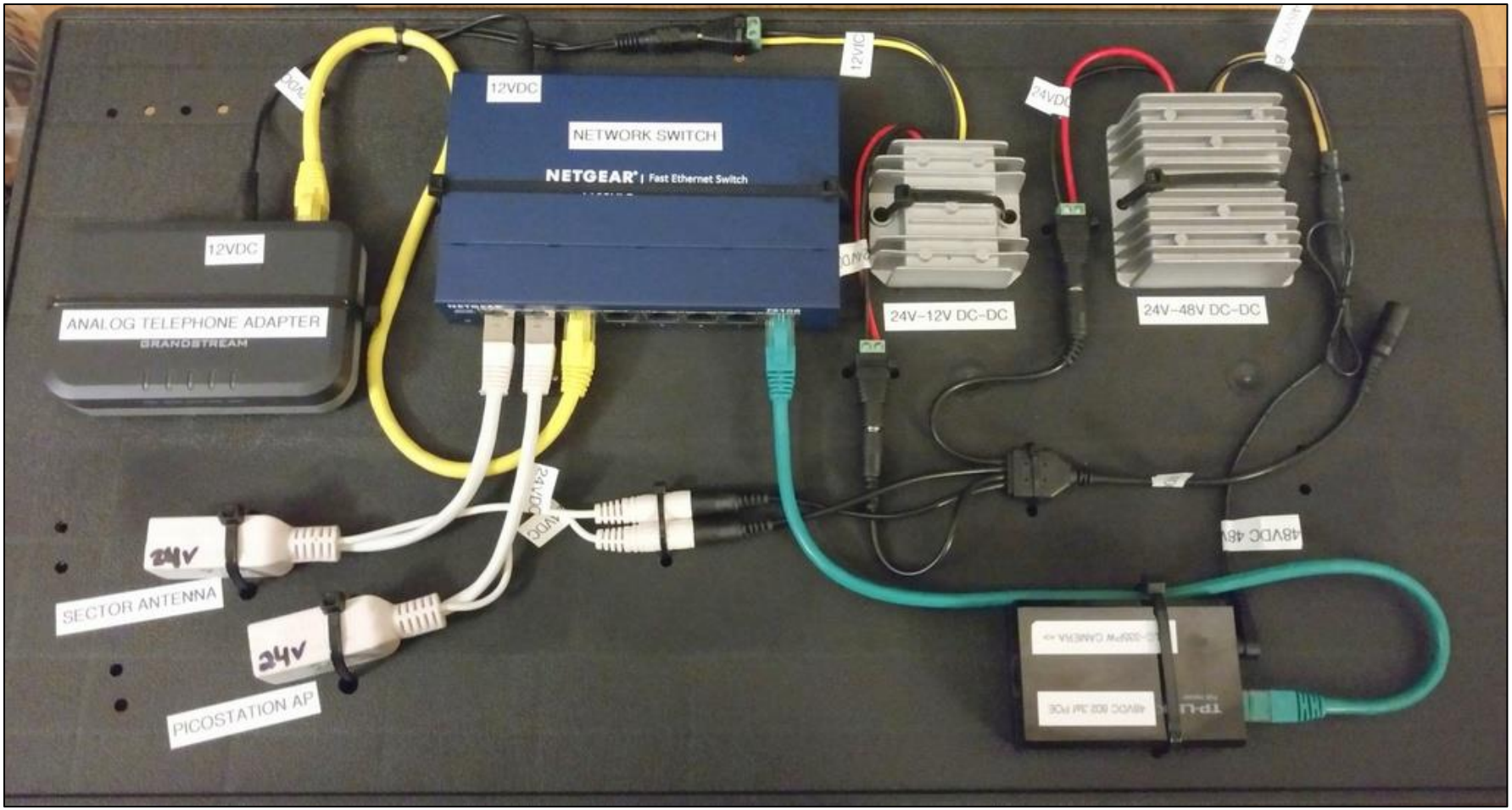
- 250W panel, 24V batteries, 2A load, 37.30Voc, 8.84Isc

Model	CMD-20	CMD-40
Nominal system voltage	12V/24V Auto Recognition ✓	
Rated Battery Current	20A	40A
Rated Load Current	20A ✓	20A
Max. PV Input Short Current	25A ✓	50A
Battery Voltage Range	8V-32V ✓	
Max Solar Input Voltage	150 VDC @ Minimum Working Temperature 138 VDC @ 25°C	
Max. Solar Input Power	12V @ 260W	12V @ 520W
	24V @ 520W ✓	24V @ 1040W
Self-Consumption	≤60mA @ 12V ≤30mA @ 24V	
Grounding	Negative	
Charge circuit voltage drop	≤ 0.26V	
Discharge circuit voltage drop	≤ 0.15V	
Temp. Compensation	-3mV/°C/2V (default)	
Communication	RSJ45	

Deployment!

ARKnet - De Anza ARK
DC Power Block Diagram
AI6MS 6/23/16
As deployed 7/16/16





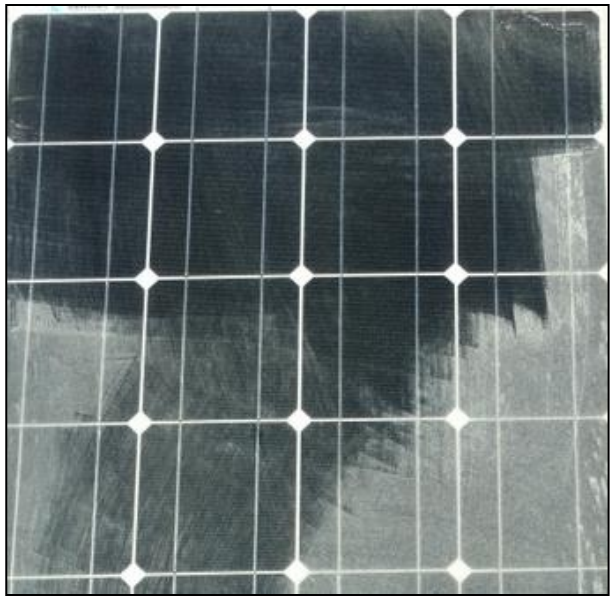
Maintenance

Maintenance Considerations

- Battery replacement
  - Typically 5 year lifetime
  - Cycling and temperature dependent
  - Most costly part of maintenance
- Panel cleaning
  - Easy to forget

Only 2 months later…

More Extreme Cases



https://www.civicsolar.com/support/installer/articles/snow-solar-panels-best-practices

Questions - Comments - Discussion

Presentation is available at: www.QRZ.com/db/AI6MS

Marcel Stieber, AI6MS@arrl.net

Want me to speak to your club or organization? Need a volunteer tower climber? Contact me!

References and Further Reading

- YouTube Will Prowse Off-Grid Solar Power: https://www.youtube.com/channel/UCoj6RxIAQq8kmJme-5dnN0Q
- https://aeesolar.com/wp-content/uploads/2017/01/2017DC-Off-Grid-System-Design.pdf
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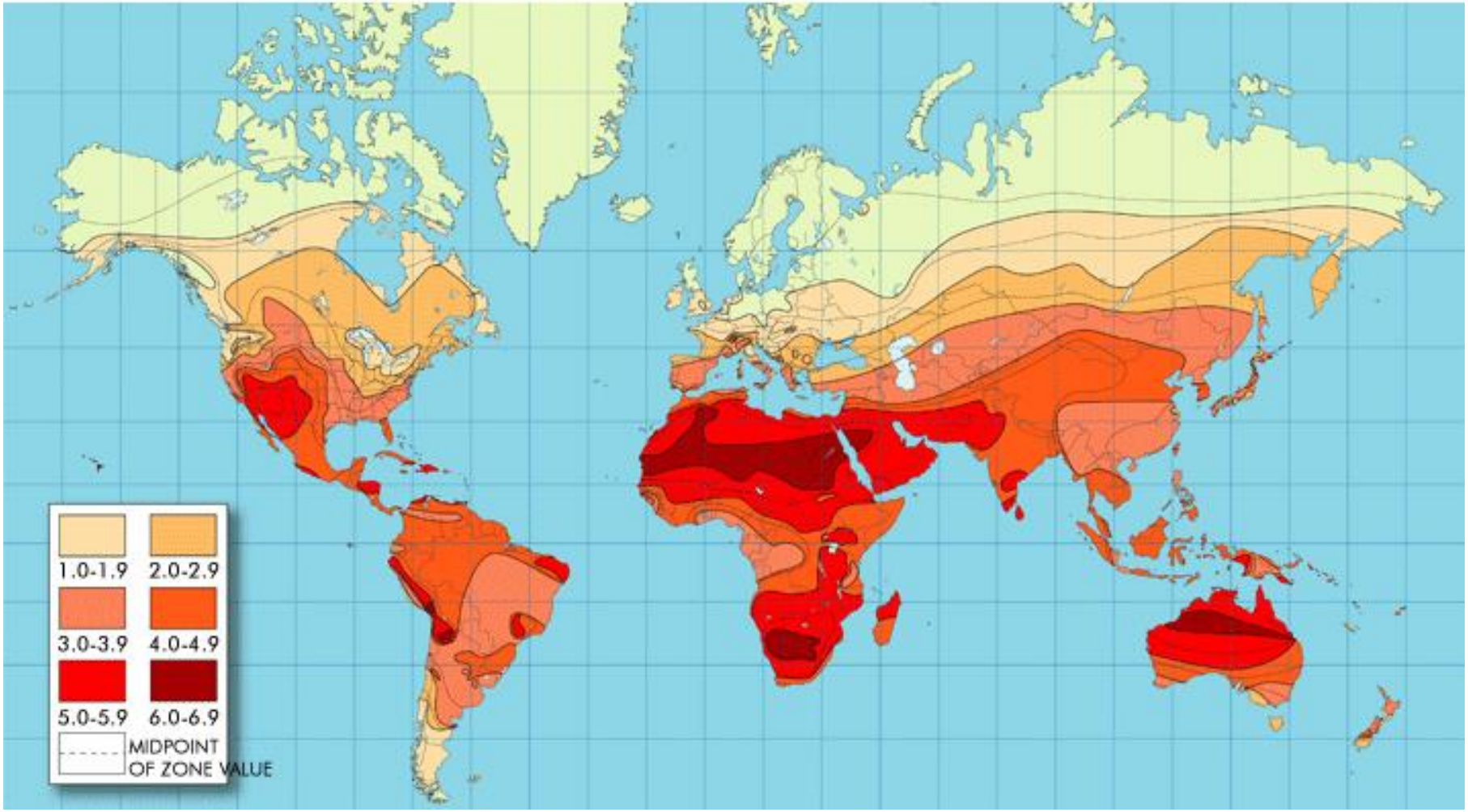
References:

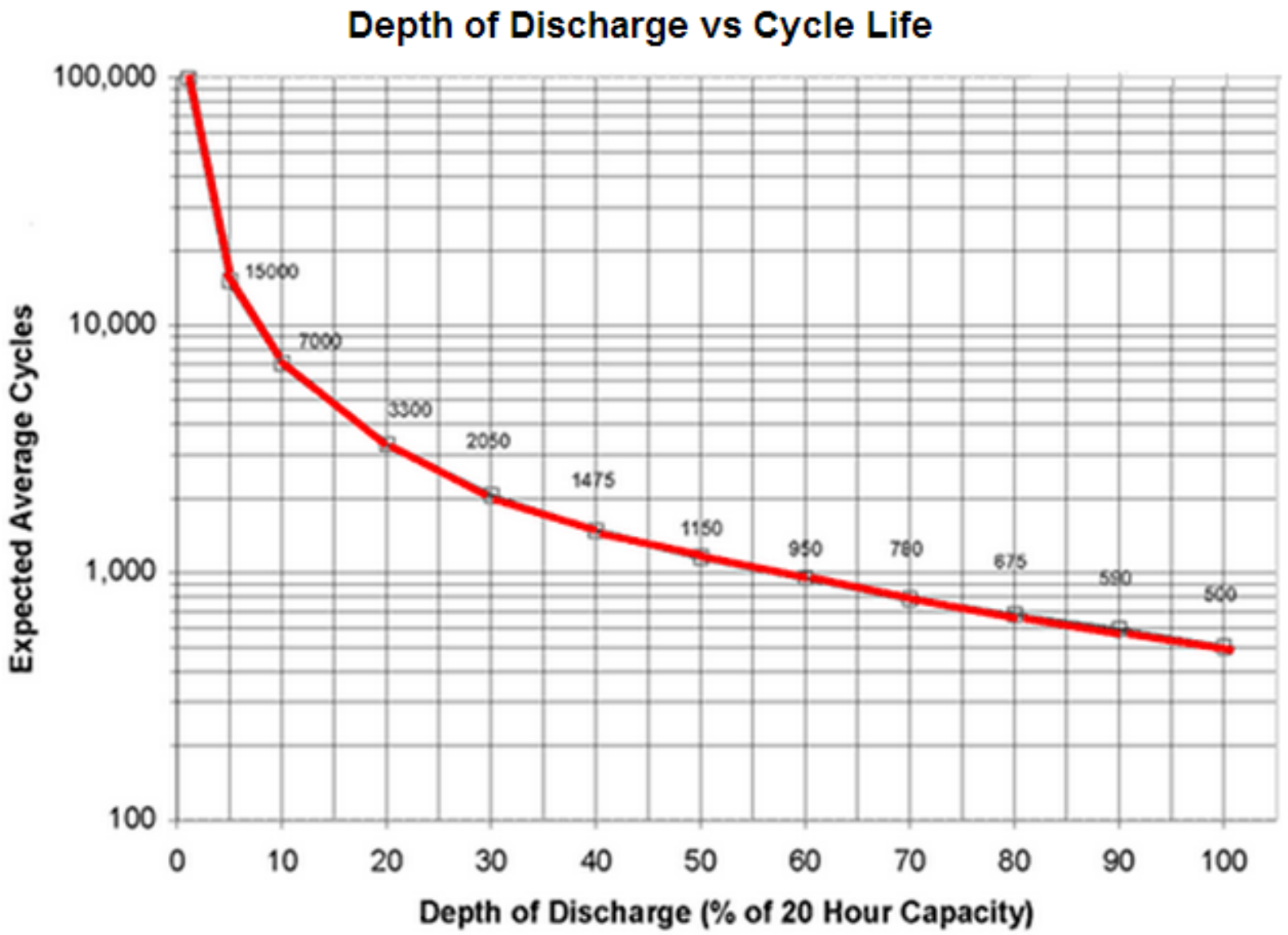
- https://mozaw.com/diy-off-grid-solar-system/
- https://en.wikipedia.org/wiki/List_of_cities_by_sunshine_duration
- https://www.solarpowerauthority.com/how-to-calculate-your-peak-sun-hours/
- https://www.solartechnology.co.uk/support-centre/calculating-your-solar-requirments

World Insolation Map

This map shows the amount of solar energy in hours, received each day on an optimally tilted surface during the worst month of the year. (Based on accumulated worlwide solar insolation data.)



http://www.solardirect.com/outdoor-lighting/solar/street/area-light/solar-insolation-map.html



https://mozaw.com/diy-off-grid-solar-system/

Another Case Study: Cheap Solar

- Temporary Repeater for Adventure Race