Off-Grid Solar Systems

for Radio Sites

Presented by

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AI6MS

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Who is this guy?

- Marcel Stieber, AI6MS
- Licensed in 2008 as KI6QDJ
- Master's in Electrical Engineer

- Cal Poly Amateur Radio Club
- 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

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-power radio site!

This is a bi-directional QSO…

So ask questions!

A brief show of hands

Forum Overview

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

Photo from WB6ECE

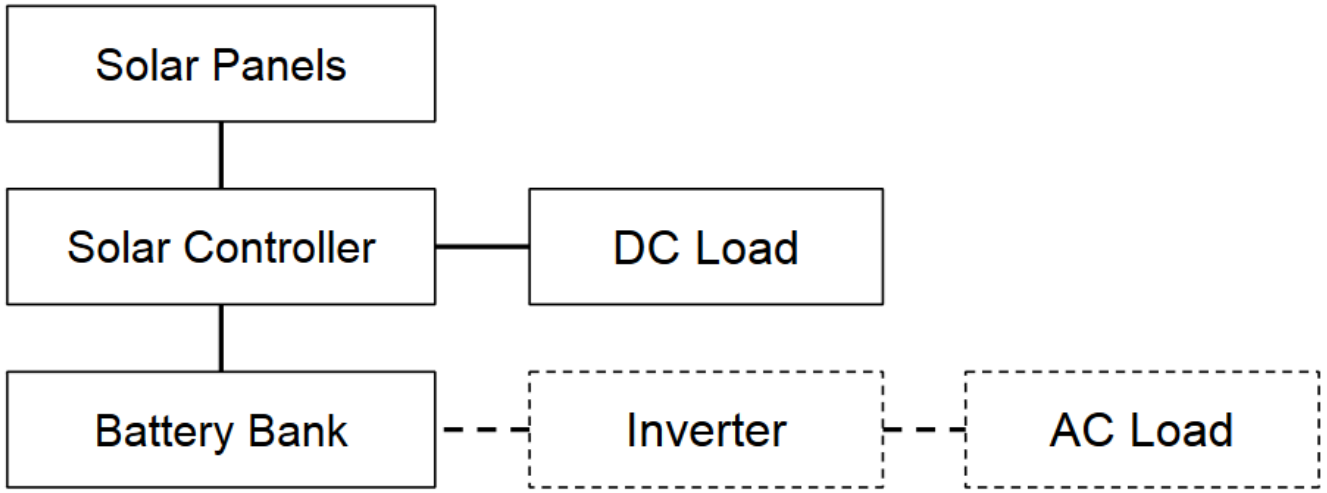
Intro to Solar Systems

Why solar?

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

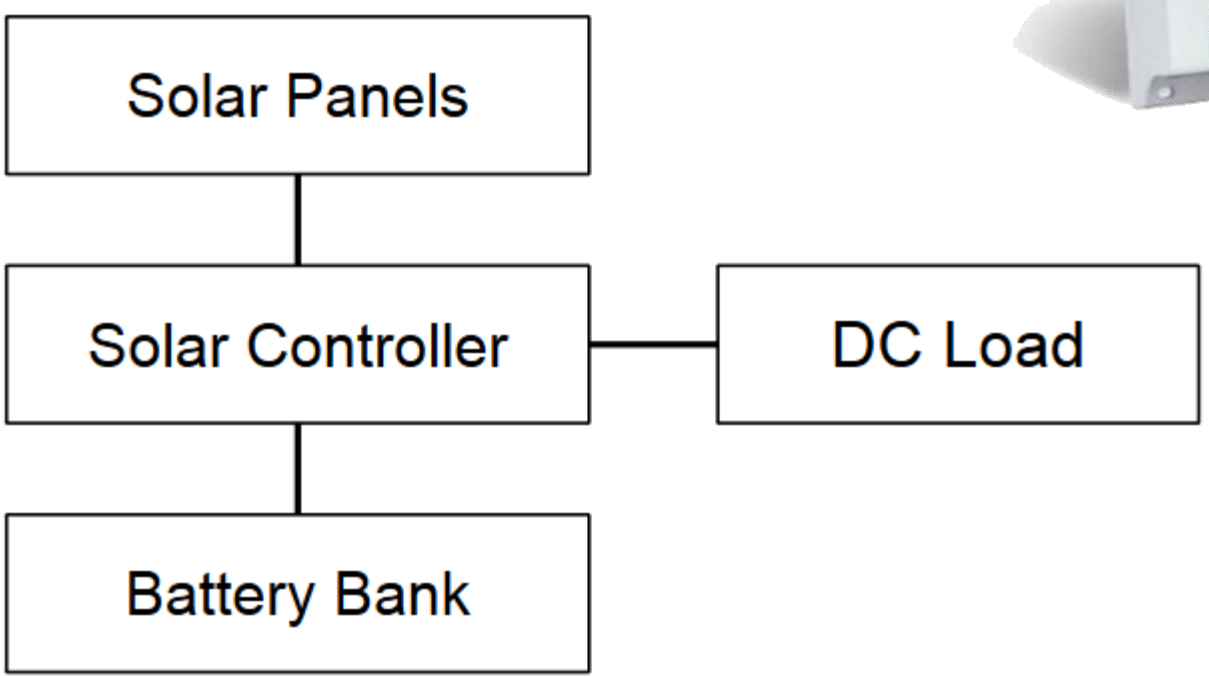
Residential vs Radio Site

- 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



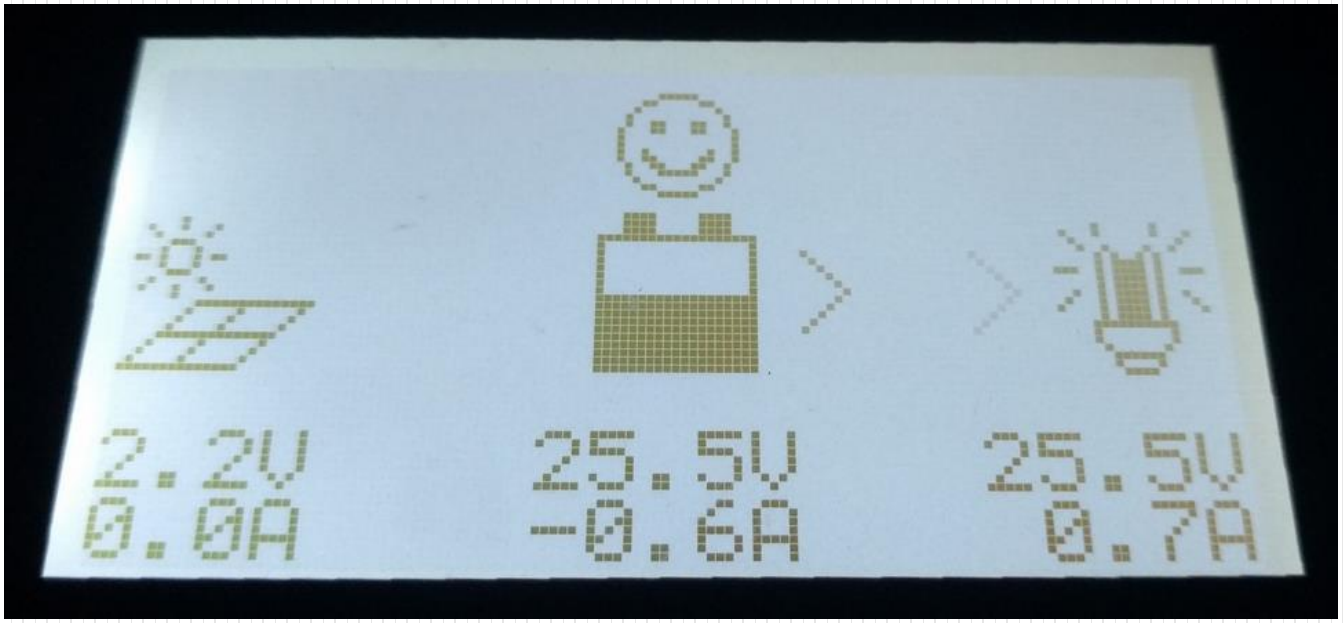
Mental Model

- 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
  - 12 Volts (plus series/parallel configurations)
  - 35-200Ah Capacity per battery
  - Low-cost per Ah

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

2pcs WindyNation 100 amp-hour 100AH 12V 12 Volt AGM Deep Cycle 100 amp-hour)
by WindyNation
$413.99 prime

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

Case Study: Battery Sizing

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

- (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

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/

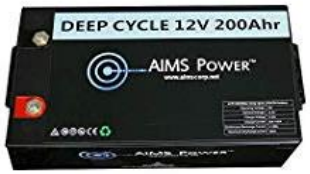
Case Study: What's this look like?

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

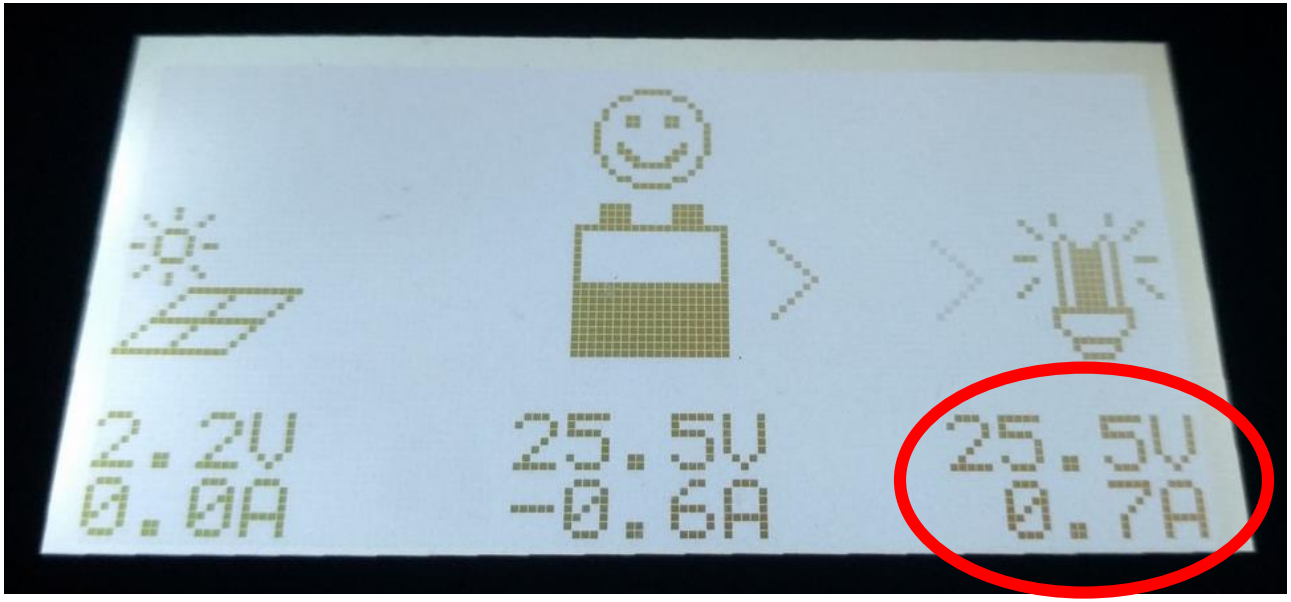
Universal UB121000-45978 12v 100AH
by Universal Power Group
$144.93 + $15.01 shipping



Sponsored
Aims LFP12V200A Black 12V Lithium Battery 200Ah
by Aims
$1,719.86 prime

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

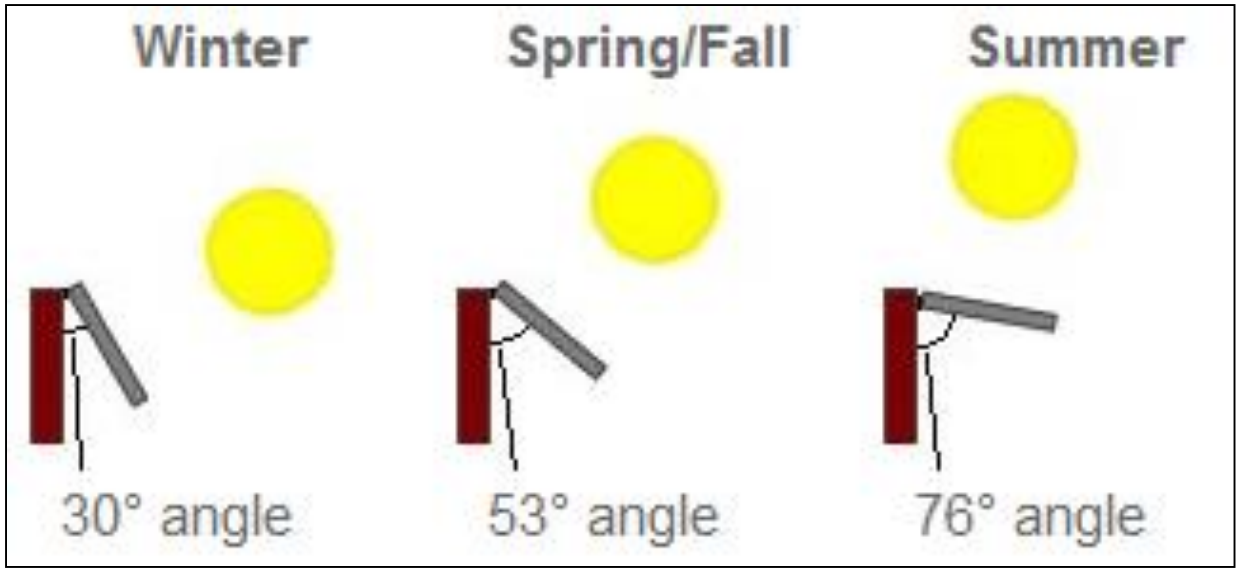
- https://www.altestore.com/store/calculators/off_grid_calculator/

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



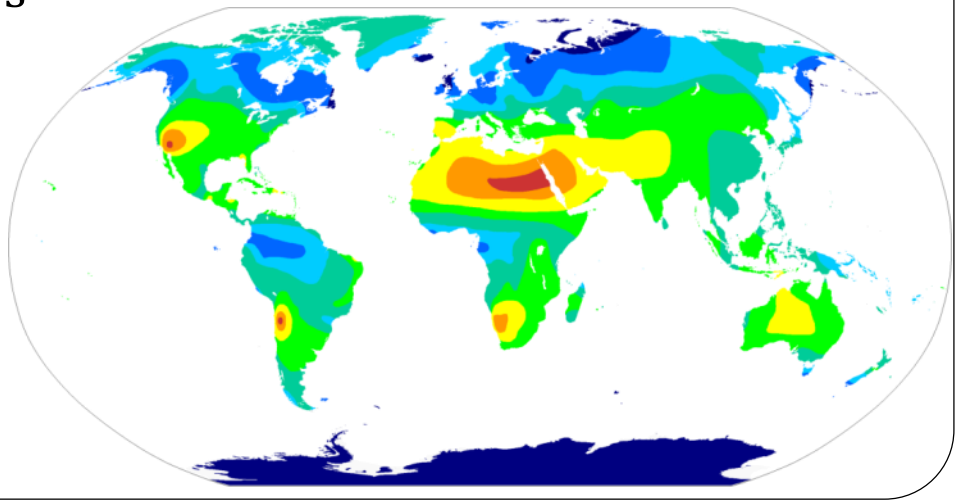
Solar Panel Sizing

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

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

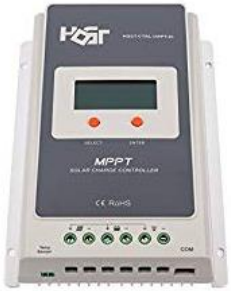
Solar Controller

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)

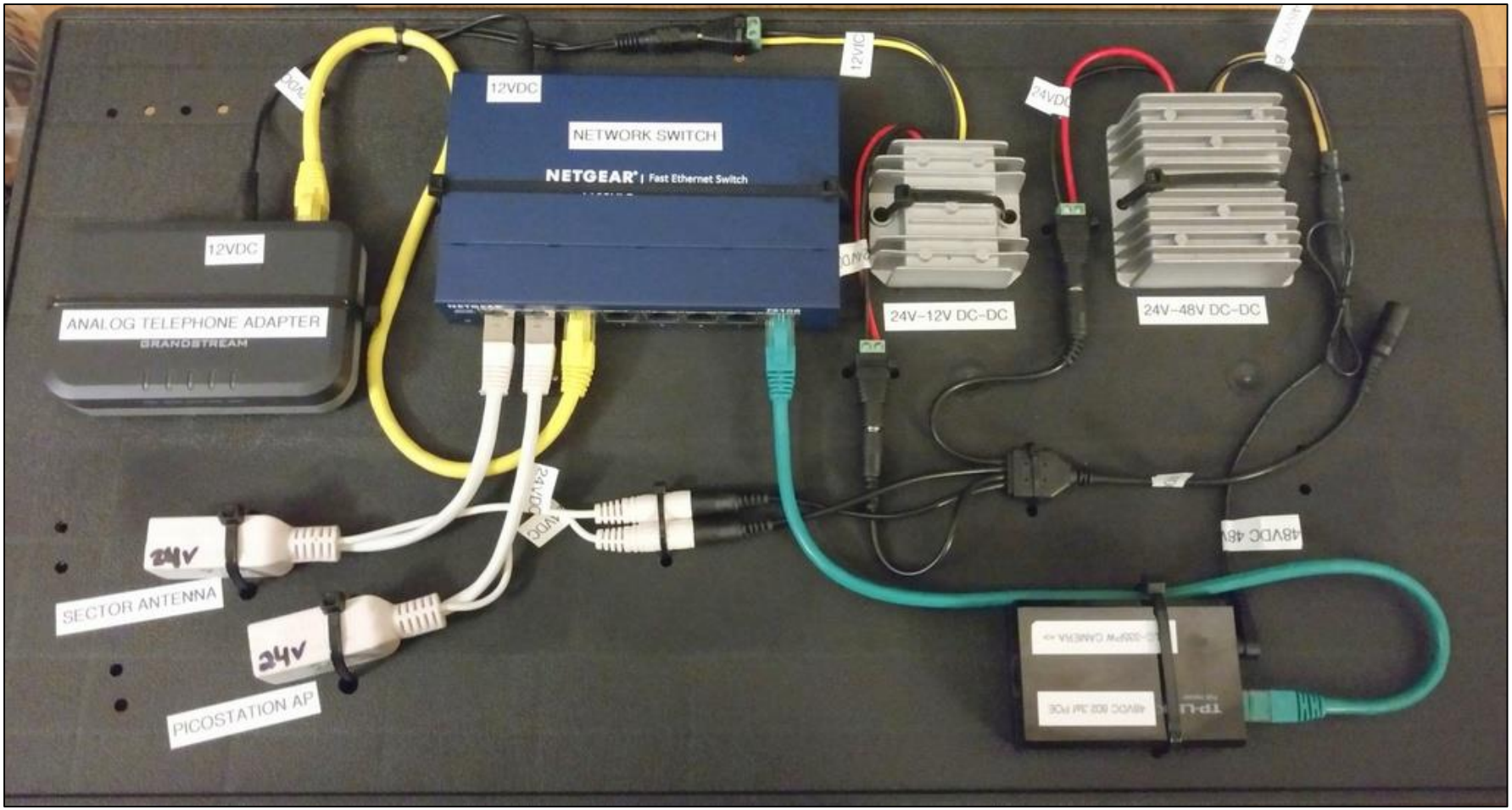
20A Commander MPPT Controller	
Nominal system voltage	12V/24V Auto Recognition
Max. PV Input Short Current	25A
Battery Voltage Range	8V -32V
Max. Solar Input Power	12V@260W | 24V@520W
Self -Consumption	1.4W to 2.6W

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!



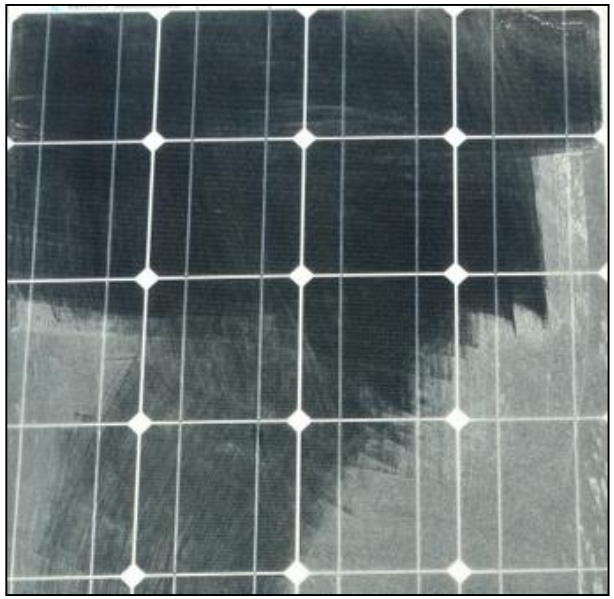
Maintenance

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 will be available at: www.QRZ.com/db/AI6MS

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

References and Further Reading

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