E-Foraging Workshops
Introduction to Off-Grid Solar Power by Alex Nathanson (12/9/16)
www.eforaging.com | info@eforaging.com


This class is designed to be a quick introduction to off-grid solar power, covering basic electronic knowledge, hardware requirements, basic off-grid solar circuit design, and determining how much power you need.

The class is created for artists/DIYer's/makers/basically anyone who isn't a "professional" with a very basic understanding of electricity and a willingness to experiment.

Introduction

What is solar power?

- Solar Panels generate electricity through the photovoltaic effect. Some material naturally absorbs photons of light and releases electrons.
- Variable i.e. dependent on available sunlight and other environmental factors.

Two types of solar power systems

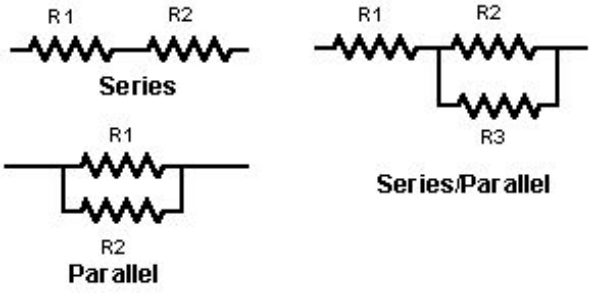
- On-grid (Connected to the public power grid)
- Off-grid (Not connected to the public power grid. This is what we're building.)

Ways to implement off-grid solar power

- Direct from solar panel to load (direct drive)
- Solar panel to capacitors to load (fly-wheel)
- Solar panel to batteries to load (energy storage)

Electrical Concepts

- A circuit is a circular path which allows electricity to flow from an area of higher voltage to an area of low voltage.
- A short circuit is when an area of high voltage is directly connected to an area of low voltage without enough resistance. This is bad!
- Series vs Parallel
- Ohm's Law V=I*R
- Watt's Law W=I*V



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AC/DC

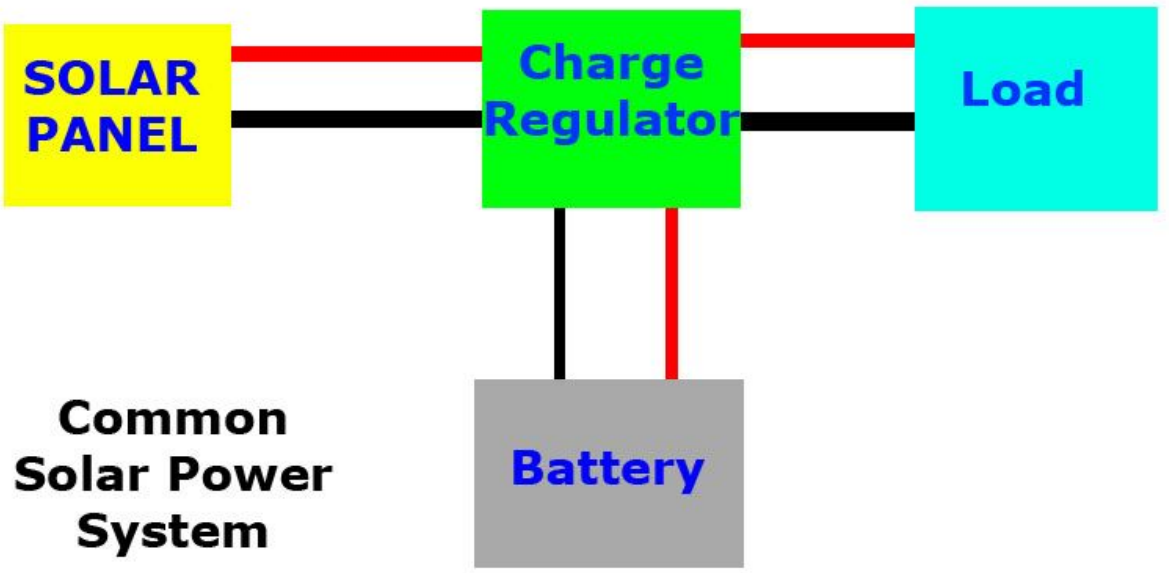
- There are 2 types of electrical currents. Direct Current, discovered by Edison, moves in one direction. This is used in batteries.
- Alternating Current, discovered by Tesla, switches directions, and is used in the national power grid.
- Inverters are used to switch from DC to AC.
- Rectifiers are used to switch AC to DC.
- Do not directly attach AC and DC power supplies and loads without the use of the proper hardware.

Safety

- Don't connect anything to a wall outlet (unless you really know what you're doing).
- Fuses should be used to protect components.
- Never mix different battery types, different brands, or different capacities in a single circuit.
- Everything discussed here is in reference to 12V DC systems, which are relatively safe. However, they can still present a small fire hazard if installed incorrectly.

Off-Grid Solar Power Systems

Main hardware components of an off-grid solar power system



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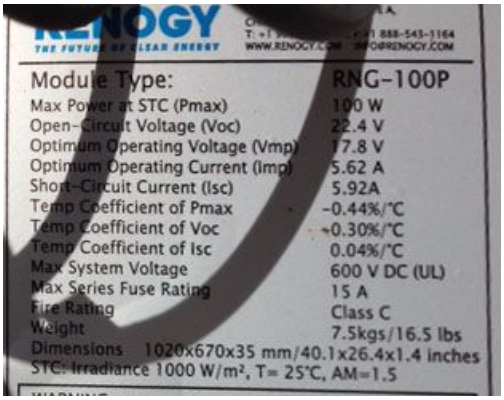
Solar Panels



- Our solar panel is sold as 12V and 100W.
- 12 volts is considered the nominal voltage, not necessarily the actual voltage.

Batteries

- Solar power batteries look similar to car batteries, but have different characteristics.
- Car Batteries, also known as starter batteries, are meant to be discharged and charged very quickly. These can work for solar in a pinch, but are not ideal.
- A typical battery engineered for solar power is called a deep cycle battery. Sometimes these are called marine batteries. These are designed for gradual charging and discharging.
- Our battery is 12V 35AH.
- 12 volts is considered the nominal voltage. When fully charged it will measure above 12V and when discharged will drop below 12V.

Charge controllers

- Charge controllers range from as low as $20 to thousands of dollar.
- Charge controllers manage charging and discharging the battery. Some charge controllers also have timers and voltage regulators.
- Determining the maximum amperage of your solar power system and matching it to the amperage rating of your charge controller is crucial.
- Nicer charge controllers will have LCD displays and provide you with a lot of information about your system.

Fuse Box

- Place fuses between the charge controller and load(s).
- Depending on your charge controller, you may want to place fuses between the solar panel, batteries, and charge controller as well.

Inverters

- Converts from DC to AC

- Most inverters are only about 80% efficient.

DC voltage regulators

- Allows you to step up or step down DC voltage as necessary.

Wires

- Wire gauges are dependent on the current (amperage) running through them.

Installation

Panel Placement

- Position your panel so it can capture the most sunlight possible. In the northern hemisphere that usually means facing south.
- If you really want to get into optimizing your solar panel you can dive into calculating the ideal angle based on your geographic position and seasonal relationship to the sun, otherwise anywhere between 20 and 45 degrees is generally fine.
- In addition to optimizing its efficiency, angling your panel helps to keep it clean.

Housing the electronics and weatherproofing

- Keep your wire runs as short as possible to avoid voltage drop.
- If you are keeping your batteries and/or electronic components outside with your panel make sure they are safe from the elements and raised off the ground.
- The simplest solution is often the best. In the past I've used a large cooler with a wooden box placed over it, all sitting on 2x4s.
- Use waterproof wire connectors if you need to make electrical connections in an exposed area.
- Use silicone caulk, marine adhesives, weather sealing paint, etc. as needed.
- While it is important to keep your equipment dry it is also good to allow for at least a little airflow. This will let any moisture that does get in evaporate. Also, some types of batteries off-gas and require air circulation.

Security

- In general, unless your panel is placed somewhere completely private, if someone wants to steal it, they can. It's extremely hard and/or costly to make something that needs to be outside 100% secure. However, you can make it difficult to disassemble.
- Placing your panel in a hidden and/or hard to reach place is the best protection.
- Lock up the steel frame of your panel.
- Use different types of screws - philips, torque, square, etc. to secure your panel in place.
- Screwing additional wood or metal over the screws you're using to actually secure the panel can further obstruct any would-be thieves.

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Determining your power needs

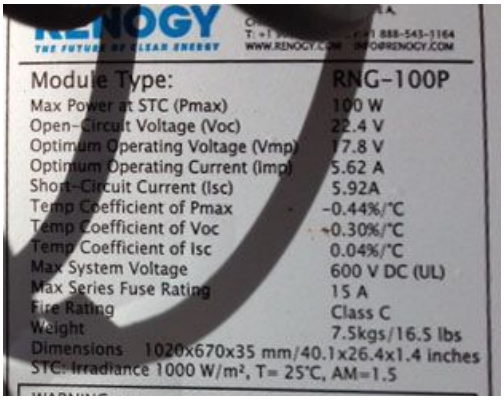
There are a lot of great solar power and battery calculators available online. This one is particularly good. https://www.batterystuff.com/kb/tools/solar-calculator.html

The exact behaviour of a given battery is dependent on it's internal chemistry.

It's important to remember that real world applications are always imperfect, especially with solar power. Weather will greatly affect the amount of energy your panel can generate. Temperature, the length of cables, bad electrical components, heat loss, etc. can all affect how efficient your system is. If you don't have a more specific number for your unique setup, factor in about 20% inefficiency to your calculations. For example, if you calculate that given battery can theoretically power a load for 10 hours, I would assume it is actually capable of power the load for only 8 hrs.

<u>If your system is less than 60% efficient something is wrong with your circuit.</u>

Calculating solar panel output



Solar panel watts/ Maximum power voltage (VMP) = Amperage output

100W/ 17.8V = 5.62A output rate (Watt's Law)

Battery capacity and capability

- 1Ah means that we can theoretically draw 1 Amp for 1 hour. This can be misleading. A 1Ah battery cannot provide 1A for an hour. This is highly dependent on the battery's chemistry, but a good rule of thumb is that it could likely supply .5A for 1 hour or .05A for 20 hours.
- As the rate of discharge increase, battery capacity decreases.
- 1Ah = 1000mAh

The capability of a battery (i.e. the ideal charge and discharge current of a given battery) is frequently measured C's.

C = Ah/1 hour
Ex. 1C of 7Ah battery is 7A.

When wiring identical batteries in series the voltage is added, but the Ah's stays constant.
When wiring identical batteries in parallel Ah is added, but voltage is constant.
2x12V @35Ah in series = 24V 35Ah
2x12V @ 35Ah in parallel = 12V 70Ah

Calculating Battery Charge Time
The ideal charge rate of a given battery depends on it's internal chemistry.
Battery capacity/ Charging current = charge time

35Ah battery/ 5.62A generated from the solar panel = 6.23 hours until theoretically fully charged

20% inefficiency: 6.23 x1.2= 7.47

Calculating the ability of a battery to power a given load (Discharge Time)

Battery capacity/ Load current = run time

35Ah battery/ 5 Amp draw of load = 7 hours
20% inefficiency: 7 x .8 = 5.6 hours

Calculating your power needs
To determine how much power you need you must start with either the current or wattage of your load

<u>If you know the current:</u>
Current of load * time you plan on running the load = Amp hours
.42A * 6H= 2.5 Ah

<u>If you know the wattage:</u>
Watts of load * time you plan on running the load = Watt hours
5W*6H = 30Wh
Wh/ Voltage of battery = Ah
30Wh/ 12V = 2.5Ah

If you are inverting DC to AC power, calculate the 20% inefficiency of the inverter.
2.5Ah/.8=3.125Ah

In addition to considering inefficiency, you also need to keep in the mind the you generally do not want to discharge a battery below 20%.
3.125Ah/.8= 3.9Ah

Additional Resources

General
Sparkfun - what is a circuit?
https://learn.sparkfun.com/tutorials/what-is-a-circuit

Solar
NASA - How do photovoltaics work?
http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/
Instructables - lots of different solar examples
http://www.instructables.com/id/How-to-Get-Cheap-Solar-Power/
Robot Room - simple solar circuits
http://www.robotroom.com/Solar-Recharging.html
Evil Mad Scientist - simple solar circuits
http://www.evilmadscientist.com/2008/simple-solar-circuits/

Solar Panel Installation
Info about how to determine the angle of your solar panel.
http://www.solarpaneltilt.com/

Batteries
Battery Stuff - calculators, good science explanations
http://www.batterystuff.com/kb/tools
MIT - a guide a battery specification, definitions
http://web.mit.edu/evt/summary_battery_specifications.pdf
Adafruit - guide to batteries
https://learn.adafruit.com/all-about-batteries/how-to-pick-the-right-battery-for-your-project#
Estimating Battery Charge Time
http://www.voltaicsystems.com/blog/estimating-battery-charge-time-from-solar/
Battery Capacity Calculations and Explanations
http://www.powerstream.com/battery-capacity-calculations.htm
Health Concerns with Batteries
http://batteryuniversity.com/learn/article/health_concerns

Diodes
http://www.allaboutcircuits.com/textbook/semiconductors/chpt-3/introduction-to-diodes-and-rectifiers/
https://learn.sparkfun.com/tutorials/diodes

Wires
Wire size chart and voltage drop calculator
http://www.powerstream.com/Wire_Size.htm