Sizing Solar Power for Off-grid Field Studies

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Selecting a solar panel, charge controller, and battery suited to supply power to a remote data collection site can be a challenging task, even for an experienced user. One of the problems is that most of the guides available for selecting photovoltaic (PV) solar power options assume that it is a permanent installation for a home or business rather than a temporary, unmanned installation. With this article, we hope to present some of the challenges and solutions to providing reliable power for autonomous field stations.

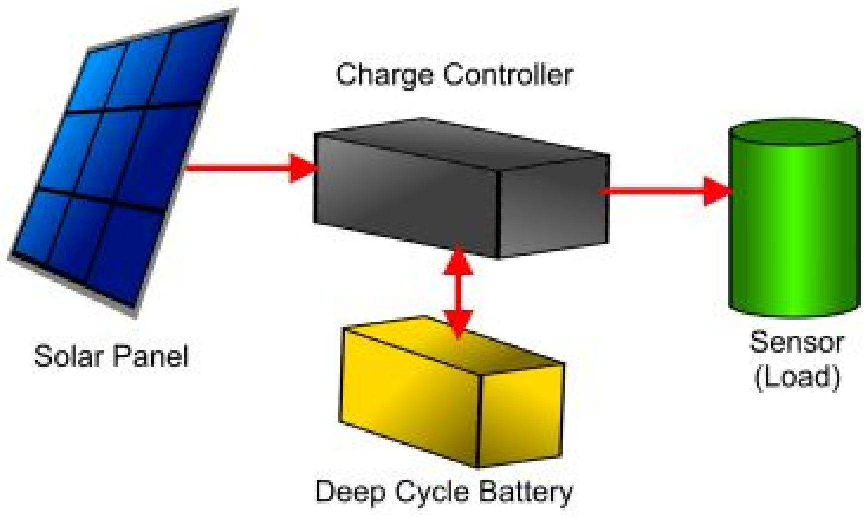

Figure 1: Typical Solar-Powered Remote Installation

IMPORTANT DISCLAIMER

Even though we are exclusively describing independent systems not connected to the electrical grid, you should still ensure that your installation is in compliance with whatever electrical, safety and building regulations apply in the jurisdiction in which you deploy it. The following guide does NOT constitute professional consultation. Solar panels and deep cycle batteries can produce potentially dangerous electrical currents capable of starting fires or causing injury and death. Always exercise caution and consult an expert if you are unsure about anything.

Determining Power Requirements

The first step is to calculate the power needed for your station (electricians call this the load). Each device to be powered should list in its specifications either its average power (in watts) or average current (in amps or milliamps). If you only have the average current, then multiply by the system voltage (typically 12 V) to get an average power, then add up all devices to get the total average power load in watts. Multiplying by 24 gives the average daily power consumption in watt hours (for a small installation, this is a more appropriate unit of measure than kilowatt hours).

CO_2 Sensor	Avg power = 1 W
Wind Speed Sensor	Avg current = 75 mA
	Avg power = 75 mA x 12 V = 0.9 W
Data Logger	Avg power = 1.2 W
Total Avg Power Load	1.0 W + 0.9 W + 1.2 W = **3.1 W**
Avg Energy per Day	3.1 W x 24 h = **74.4 Wh** (0.0744 kWh)

Sample Load Calculation

Determining Battery Requirements

Now that the daily energy consumption is known, we can determine the battery required. A deep-cycle, sealed lead-acid battery is typical for this type of application since it operates over a wide temperature range, is usable in any orientation and, unlike a flooded lead-acid battery, it requires no maintenance. In the future, lithium-ion battery packs (typically found in laptops and cellphones) may be a good choice due to their lower weight per capacity, but currently these are expensive, require specialized charging systems, and are difficult to ship due to safety regulations. Sealed lead-acid batteries are available in two types: absorbed glass mat (AGM) and gel cells. Both are appropriate for unattended operation, with AGM batteries being slightly less expensive and gel cells allowing a slightly higher ambient operating temperature. Whichever you choose, be sure that your charge controller supports that type of battery (more on charge controllers later).

Avg Energy per Day	74.4 Wh
Multiply by 3 days autonomy	74.4 Wh x 3 = 223.2 Wh
Max 50% discharge	223.2 Wh x 2 = 446.4 Wh
10% derating for inefficiency	446.4 Wh x 1.10 = 491.04 Wh
Temperature derating (@ 10 °C)	491.04 Wh x 1.11 = 545.05 Wh
Divide by 12 V	545.05 Wh / 12 V = **45.4 Ah**

Sample Battery Calculation

Calculating Battery Capacity

Battery capacity is typically given in units of ampere hours (Ah). To calculate the ampere hours needed, take the average daily energy consumption calculated earlier and multiply by the number of days of autonomy you would like the system to have (i.e. the number of days in a row that the location might have complete cloud cover). To maximize battery life, the battery should not be discharged more than 50%, so multiply the resulting number by 2. Then derate 10% for inefficiencies like self-discharge. If the ambient temperature during your deployment will be less than 25 °C, you should also derate the battery capacity for temperature effects. Each battery manufacturer will have its own specifications, but the one shown in the example is typical for AGM batteries. Finally, divide the result by the system voltage (12 V) to find the desired capacity in Ah and chose the battery with that rating or higher.

Ambient Temperature	Battery Capacity	Multiplier
25 °C	100%	1.00
20 °C	95%	1.05
10 °C	90%	1.11
5 °C	85%	1.18
0 °C	80%	1.25
-5 °C	75%	1.33
-10 °C	70%	1.43
-15 °C	60%	1.67

Table 1: Battery Derating for Ambient Temperature

In this example, 45.4 Ah are needed, so a battery with a 50 Ah capacity would be adequate.

How Much Solar Energy is Available?

The next step is determine the amount of solar energy available at the deployment site. This consists of three main components: the angle and timing of sun (which can be calculated for any location on earth based on the latitude, longitude and date), the meteorological effects (which can be calculated for areas near a weather station based on historical data), and the shading effects of the local topography (which generally requires prior access to the deployment site and specialized equipment).

Calculating Peak Sun Hours

The most important figure to calculate for your potential site is the Peak Sun Hours (PSH) per day. This is not a simple measure of daylight hours but rather the equivalent number hours of an amount of standardized solar radiation (1 kW/m^2). In the graph below, the red line shows the amount of solar radiation received during a day. The blue line show the equivalent number of PSH. The area under both curves is the same, but since PSH is in standardized units (the same standards that solar panel manufacturers use to rate their panels) this number can be used to choose a solar panel appropriate to your application.

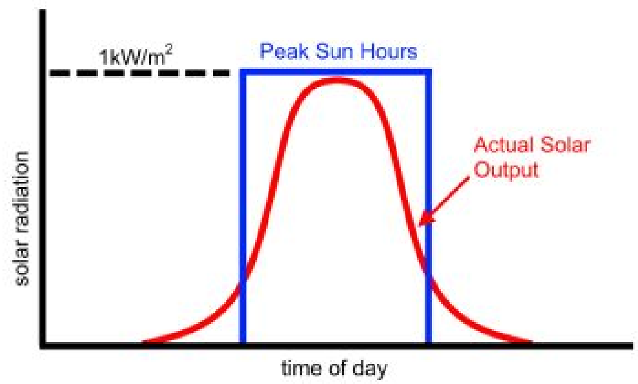

Figure 2: Peak Sun Hours

While there are maps showing peak sun hours for various locations, they are not always useful for remote installations. They often show only highly populated areas like the continental US or Western Europe. More importantly, they generally show the yearly average peak sun hours. This can be useful for determining the economic feasibility of a long-term residential site. It would be very expensive for a solar home to size it's panels based on the worst month of the year since it would have unused excess capacity for the rest of year; instead they generally design for the average and supplement the solar power with wind, diesel generators or a grid connection during the lean months. Since a remote autonomous installation does not have these options, we must design for the worst month of the year (or for a short term deployment, the worst month of the deployment).

Optimizing for Solar Angle

While most guides recommend either setting the angle of the solar panel to the location's latitude in degrees or adjusting the angle several times throughout the year, neither of these are suitable for this application since the site will be unattended and we need to design for the worst month rather than the average. Set the angle to get the maximum benefit at solar noon on the winter solstice (December 22 in the northern hemisphere), or the day of your deployment that is closest to the winter solstice if it is less than a full year. This angle can be found by the formula $A = L - (23.45° \times \sin(T \div 365.25 \times 360°))$, where L is the latitude of the installation, T is the number of days from spring equinox (March 21st), and A is the ideal panel angle for that day. Alternatively, websites like SunCalc can be used to determine the angle of the sun to the ground (referred to as the altitude) for any given location, date and time. The azimuth is the compass angle the panel should point, which is generally due south (though when doing the installation, be sure to correct for the local magnetic declination at your site).

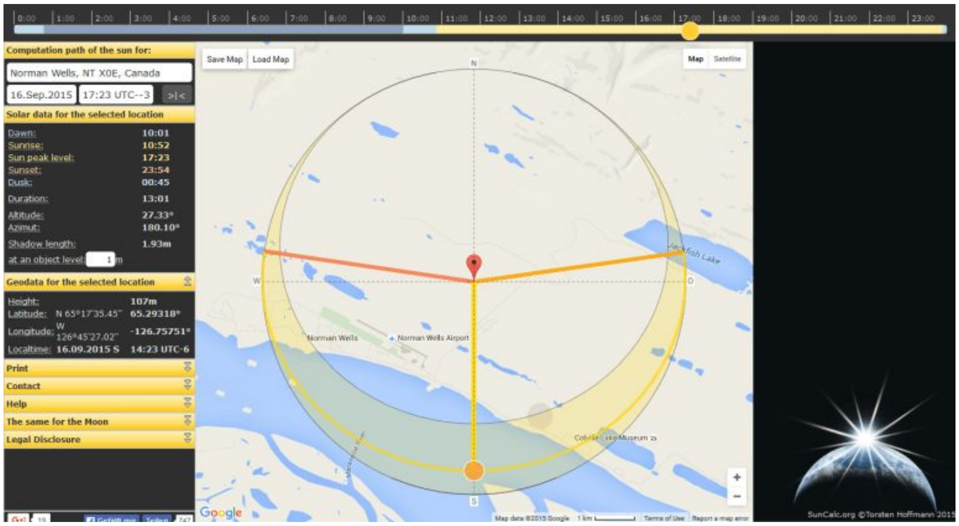

Figure 3: Reading sun angles from SunCalc.org

You may have little control over the placement of the data collection site, but ideally it will have no large buildings, trees or other obstructions blocking the view of the south-east to south-west horizon (if located in the northern hemisphere; north-east to north-west horizon for the southern hemisphere). If there are obstructions that cannot be removed, you may want to consider moving to higher ground if possible, or mounting your solar panels on a pole to minimize the effect of shading from the obstructions. It is difficult to quantify the effect of shading without specialized equipment, however there is an Android app available called "Scan the Sun" which uses your phone's camera, GPS and compass to perform a decent site analysis including shading calculations.

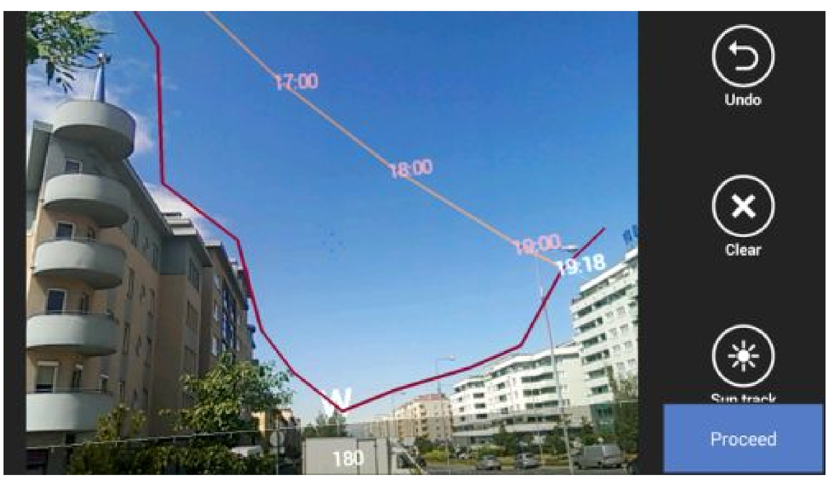

Figure 4: ScanTheSun Android App Display

The calculations for daily peak sun hours (or solar insolation) are complex to perform manually. Fortunately there are many calculators available online. One of the best regarded is the PVWatts Calculator provided by the U.S. National Renewable Energy Laboratory. While it was designed primarily for residential installations within the United States, it works well for any location worldwide. The calculator initially asks for a street address as a location, but if you enter an address near to your desired location, you can manually drag the marker to an “off-grid” location. Weather data from the nearest available weather station is used to compute the meteorological effects.

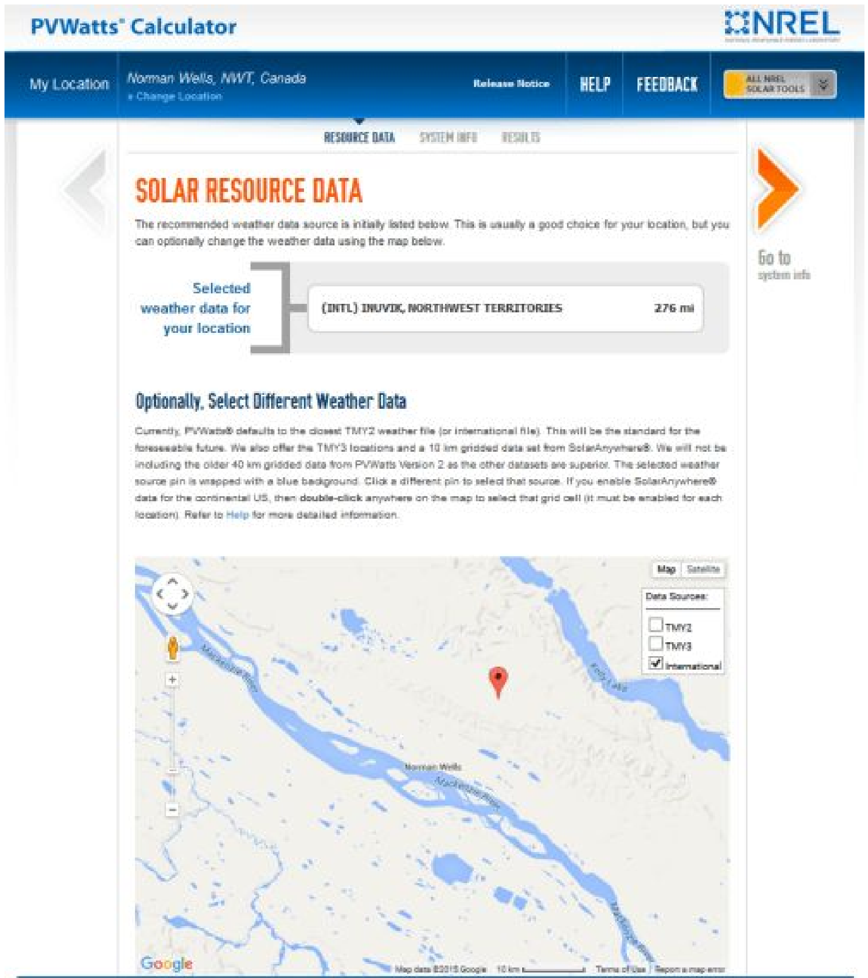

Figure 5: Entering Location into PVWatts Calculator

In the “System Info” screen, you can select a PV panel size (the minimum is 0.05 kW or 50 W) and panel type. Array should be “Fixed (open rack)”. You can accept the recommended tilt angle and azimuth or enter the optimized angles you calculated in the earlier stage. The economic parameters are not applicable and can be left blank. The “System Loses” can be refined if you know these values for your system or you can just accept the defaults. Under “Advanced Parameters”, since we are running a DC-only system, set the “DC to AC Size Ratio” to 1 and the efficiency to 99.5% (the highest the software allows).

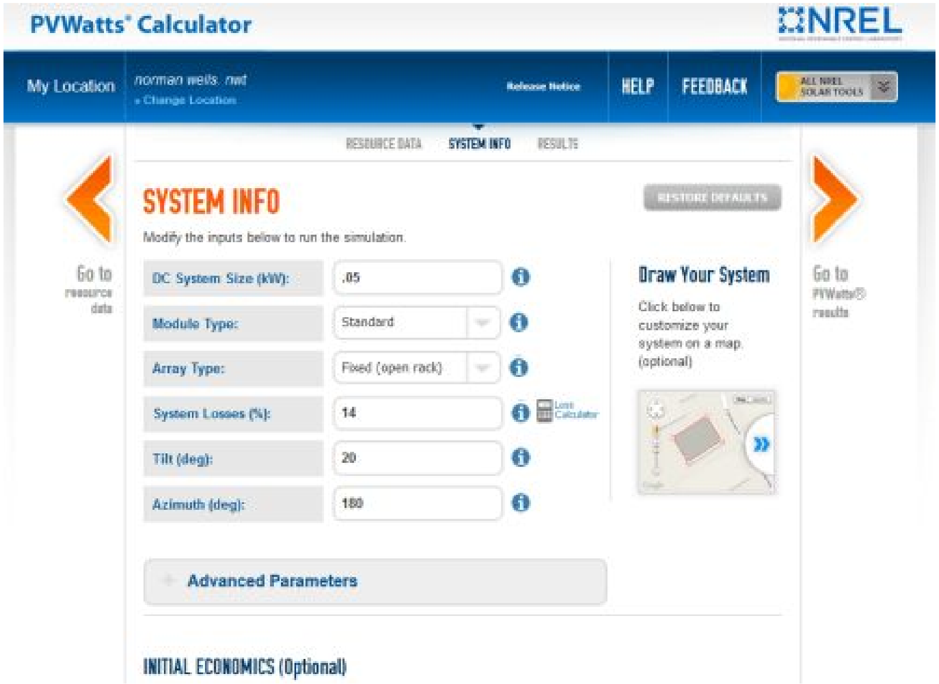

Figure 6: Entering system information in PVWatts Calculator

You can then go the Results page and see a summary showing the solar radiation for each month in kWh/m2/day (also known as Peak Sun Hours per day). The column marked “AC Energy” is the useable energy produced for that month after system loses in kWh. We calculated earlier that our sample system needs 74.4Wh per day. Multiplying by 30, this system would need 2232 Wh or 2.2 kWh per month. If the energy produced in the worst month of our deployment is less than 2.2 kWh, we can go back to the System Info and select a larger panel, then check the results again. More detailed monthly and hourly results can be downloaded in CSV format.

Another on-line calculator with fewer options but much easier to use can be found at the EcoWho website. Rather than average daily output for each month, it simply shows the energy produced in the best and worst day of the year.

Sizing your PV Panels

Photovoltaic panels are a rapidly maturing technology and as volume increases, prices have been dropping. If you haven’t priced panels for a few years, your instinct may be buy the smallest panel you think you can get away with, but this would be a mistake. Higher wattage panels in many cases are only slightly more expensive than lower wattage panels. In terms of price per watt, the best value is currently in the 20 volt panels commonly used in grid-tied residential applications which can often be found for the same price as a 12 volt panel with half the power rating. These panels can be used with 12 volt batteries if you have the right charge controller.

Figure 7: EcoWho Solar Panel Output Calculator

Once your PV panel has been selected, you should consider a mounting rack. Having an adjustable rack will make it straightforward to optimize the angle of the panel for maximum energy collection as well as easing reuse of the system at a different location. An automatically tracking panel rack will produce more power by continuously adjusting the angle of the panel to be perpendicular to the sun's rays, but the added cost and complexity is generally not advisable for this type of application.

Choosing a Charge Controller

Since solar panels put out varying voltage levels depending on the intensity of the sunlight and batteries require different voltage levels depending on the current charge level, a device called a Charge Controller (sometimes referred to as a regulator) is required to regulate the voltage and prevent over-charging the batteries as well as preventing reverse voltage (so power doesn't flow out of the batteries and into the solar panels at night). Charge controllers may also provide additional fuse or circuit breaker protection. There are several types of charge controllers available. Ensure that the controller you purchase is designed to work with the type of batteries you have chosen, as different batteries types have difference charging profiles. While they are slightly more expensive, a Maximum Power Point Tracking (MPPT) controller is generally recommended for this type of application as it is the most efficient and wastes less power in converting voltages than Pulse Width Modulated (PWM) controllers. Many MPPT controllers will also allow you to use commonly available (and thus cheaper) 20 volt panels designed for grid-tied applications without wasting the extra voltage they provide when connected to a 12 volt battery. Another feature that is highly recommended is a Load Control or Low Voltage Disconnect (LVD). This disconnects the load from the battery when the battery is nearly depleted, preventing an over-discharge that can permanently damage the battery.

Charge controllers are rated by current and voltage. For all systems, the nominal battery output voltage should match the voltage of your batteries (typically 12 V for small installations). For PWM controllers, the nominal PV input voltage should also match the battery and panel voltage (again, typically 12 V). For MPPT controllers, the nominal PV input voltage should greater than or equal to the panel voltage, and the maximum PV open circuit voltage should be greater than or equal to the panel open circuit voltage (V_{OC}). The continuous-use input current rating of the controller should be greater than or equal to the short circuit current of the panel (I_{SC}) multiplied by a 1.25 safety factor. If the current rating of the controller is not specified as for continuous use, then use a safety factor of 1.56 instead.

Enclosure Considerations

The battery and charge controller need to be enclosed in a weather-proof box, however it is important that the box is not air-tight. In the event that a lead-acid battery is overcharged, some hydrogen gas may be discharged. Normally this gas would dissipate harmlessly into the atmosphere, but in a confined, air-tight box enough gas may build up to become dangerous. Thus it is a good practice to use an enclosure with a vent to prevent the buildup of gas.

Wiring and Fuses

If your charge controller does not include integrated fuses or circuit breakers, it is good practice to add in-line fuses on the positive wires from the solar panel(s) to charge controller, charge controller to battery, and charge controller to load. Fuses and wires should be sized based on the maximum current for that wire multiplied by a 1.25 safety factor. Wires should be kept as short as possible to minimize losses (especially from the controller to the battery which carries the highest current in a MPPT system). Wire size should be selected to handle the maximum current (plus 25% safety factor), though using a wire size larger than the minimum is fine and will reduce losses, particular in runs which are necessarily long, like from the panels to the controller.

The Eco Online website has a useful wire sizing calculator, although it uses cross-sectional area instead of American Wire Gauge (AWG) to define the wire size. The table below can be used to cross-reference AWG to area.

AWG Wire Size	Cross-Sectional Area (mm^2)	Recommended Fuse Size (A)
22	0.33	3
20	0.50	5
18	0.82	7
16	1.6	10
14	2.0	15
12	2.6	20
10	3.3	30

Table 2: Wire Size Reference

That's it!

The guidelines presented here are somewhat conservative. Additional constraints like size, weight and cost may force you to compromise on certain aspects of the design.

Good luck with your solar-powered field study projects, and feel free to add comments to the original blog article (www.eosense.com/blog).

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