Recommended Design Practice of Off Grid Solar PV Systems

The design process is a fairly simple and straight forward that doesn’t require a lot of technical knowledge. What follows is based on using MPPT Charge Controllers because they are the most efficient and economical solution for systems requiring a 200 watt or higher solar pane. The initial steps are:

- Determine the load in energy for a 24-hour period. Not the watts, but the watt-hours.
- Determine the size of the solar array to be used.
- Determine the battery size and type.
- Determine charge controller size

DESIGN EXAMPLE

The following example is a rough estimate to take to a system designer to discuss cost and objectives. He/she will then fine tune the system based on actual components, cable distance, etc… Our basic objective in this simple example is to provide power to a 250 watt load (light bulb) for 24 hours per day in two different cities (Tucson AZ, and Seattle WS) with 90 % availability. FWIW this is a system I have designed many times using remote cell radio sites. The transmitter is continuous 250 watt load, and the system will be a typical sized system that can be used in a home application. The only difference is radio sites are designed for 99.99% availability and this one will only be 90%. Getting from 90 to 99.99% greatly increases the cost with a larger solar array, larger batteries, and a standby generator set.

1 DESIGN FOR WORST CASE

In this example the worst case is simple to determine because the load is continuous 24 x 7 x 365 of a 250 watt light bulb. So the worst case is the months of December and January when the Solar Insolation is at its lowest point of the year. In some instances, the worst case for the load might be in the summer. Therefore you make two designs, one for winter and one for summer, and then use the larger of the two systems.

So in this example we need to determine the energy needed in a 24 hour period. This is done with watt-hours. To determine the watt-hours is straight forward of Watts x Time (in hours). So 250 watts x 24 hours = **6000 watt-hours or 6 Kwh** in a day or 24 hours. Make note of this number as it will be needed latter.

2 IS THROW IN A FUDGE FACTOR

To account for overall system losses in the wiring, charge controller, battery charge efficiency, and inverter you multiply the total 24 hour load energy by 1.5 So 6000 x 1.5 = **9000 watts** or 9 Kwh. Now take note of this figure. FWIW if using a PWM Controller the Fudge Factor is 2

3 DETERMINE SOLAR INSOLATION IN HOURS

Most solar map data are given in terms of energy per surface area per day. No matter the original unit used, it can be converted into kWh/m2/day. Because of a few convenient factors, this can be read directly as "Sun Hour Day" The number you want to use in this example is for December since December days are the shortest. Tucson is shown to receive 5.6 kWh/m2/day in December.. For Seattle, the number is 1.2 Kwh/m2/day. So we need to note **5.6** and **1.2** for our Sun Hour Day as it will be used to determine the solar panel array wattage.

4 DETERMINE THE SIZE OF THE SOLAR PANEL ARRAY.

The size of the array is determined by the adjusted daily energy requirement using the Fudge factor number divided by the sun-hours per day. So for Tuscon 9000 wh / 5.6 h = 1607 watts, round up to **1800 watts**. For Seattle 9000 / 1.2 = **7500 watts**. Note the huge difference; it is because of the Solar Insolation. Location matters and will greatly affect system cost.

5 DETERMINE BATTERY SIZE

Determining battery size is very simple. All batteries will last substantially longer if they are shallow cycled. That means discharged only by about 20% of their capacity in a given day. Whereas deep discharge means that a battery is discharged by as much as 80% of its capacity. Second point is no lead acid battery should ever be discharged more than 50%. Below 50% soft lead sulfate crystals harden on the plates which reduce capacity and shorten battery life substantially. So with this said the battery capacity is calculated to be 5 full days. So in real application you have 2.5 days of usable capacity to allow for cloudy days before reaching the 50% discharge.

To figure the daily load, go back to the original load number before the fudge factor—that is, **6000** watt hours. Battery capacity = Daily Watt Hours x 5. So we need 6000 watt hours x 5 days = 30,000 watt hours or 30 Kwh.

Now that we have the battery capacity in Watt Hours we need to convert to Amp Hours. To find the Amp Hours we need to select a battery voltage. Amp Hours = Watt Hours / Voltage. To select battery voltage is based on panel wattages vs controller size. MPPT charge controllers have maximum panel wattage input vs the controller's current rating in AMPS. MPPT controllers typically come in 20, 40, and 80 amps. So selecting battery voltage is very important. As a general rule you want to run the battery voltage as high as economically possible.

I have some general rules of thumb for battery voltage selection:

1. Never use 12 volts. 12 volts is for toys and RV's
2. Panel wattages 300 watts to 1000 watts use 24 volt battery
3. Panel wattages higher than 1000 up to 4000 use 48 volt

Based on those rules both Tucson and Seattle will use 48 volt batteries. So the battery capacity in Amp Hours = 30,000 wh / 48 volts = 625 Amp Hours.

6 DETERMINE CHARGE CONTROLLER SIZE IN AMPS

It is very simple, Charge Controller Output Amps = Panel Wattage / Battery Voltage. So for Tucson the minimum MPPT Charge Controller is; 1800 watts/ 48 volts = 37.5 amps. So Tuscon requires a 40 amp MPPT Charge Controller.

OK for Seattle you are in for a huge expense because 7500 watts / 48 volts = 156 amps. There is no such thing as a 156 amp MPPT Charge Controller. MPPT charge controller's typical sizes are 10, 20, 40, 60, and 80 amps. So in Seattle you will need 2 units of 80 Amp MPPT Charge Controllers supplying a common battery. That means you need to break the 7500 watt panels into two separate 3750 watt systems each with its own 80 amp MPPT Charge Controllers. Remember what I said location matters.

7 CONCLUSION & LAST COMMENTS

We need to re-visit batteries for a moment. Flooded Lead Acid (FLA) are the least expensive and last the longest of the lead acid chemistry. However they have one drawback and that is they have the highest internal resistance. What this mean is the maximum charge rate they can be charged with is C/8 where C = the battery 20 hour discharge rate Amp Hour Capacity. So the maximum current we can apply to a FLA 625 AH battery is 625 AH / 8 h = 78 amps. So for the Tucson we can use FLA batteries.

More bad news for Seattle because the charge rate exceeds C/8 for FLA batteries. 156 amps is a C/4 charge rate. So in Seattle you are forced to use AGM batteries. AGM is a lead acid battery which is a Sealed Lead Acid (SLA) or sometimes called a Valve Regulated Lead Acid (VRLA). AGM batteries have low internal resistance but they do not last as long as FLA batteries. To add insult to injury AGM batteries cost roughly 200% more than FLA.

Now here is the real fun and educational part. Based on the USA national average price of $0.101/Kwh each of these two design examples generate 6 Kwh/day and cost or $0.61/day or **$1106 in 5 years.** Batteries need replaced on average every 5 years. So the Tucson system major equipment cost (panels, charge controller, and battery only) roughly **$8200.** After 5 years you are looking at a $**4500 battery** replacement cost. So for the first 5 years you have volunteered from paying $0.101/Kwh to $0.75/Kwh or a 740% rate increase.

You folks in Seattle are really in for a shock. You initial equipment cost are $24,600 so for the first 5 years you are now paying $2.25/Kwh or a 2227% rate increase. In 5 years you are looking at $9000 battery replacement cost.

So be careful what you ask for because being GREEN can take on a whole different meaning like; Your GREEN becomes my GREEN bank account balance.