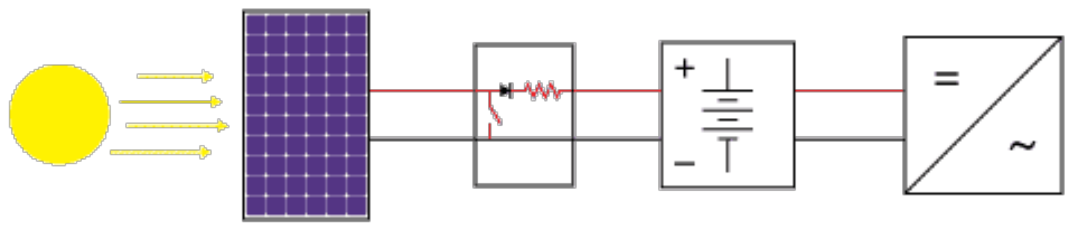
Excerpt from *Off Grid Solar*
By Joe O'Connor

How Off Grid Solar Works



The Sun (Fuel Source)

With a solar power system you never need to purchase the fuel; the fuel is wirelessly transmitted from a fusion reactor that is safely placed 149.6 million kilometers away. The sunlight that hits earth is equivalent to 170,000,000 gigawatts of power, and in just eight minutes enough energy smashes into the earth's surface to meet global electricity needs for an entire year. The Sun is the most abundant fuel source available to us and with technology developed in the past 50 years it is incredibly easy to capture.

Solar Panel (Sunlight to Energy Converter)

Photovoltaic (PV) solar cells convert the sun's flying photons into an electrical charge. Photons from the sun hit electrons on the top layer of the PV cell pushing them through a boundary layer where they end up on the back side of the cell. The electrons want to return to where they came from so they rush back to the front of the cell through the path of least resistance. This electron movement is what creates power in the solar panel.

Charge Controller (Energy Manager)

Charge Controllers protect the battery and optimize the energy coming from the solar panels. Consider this as a traffic guard that directs energy flow based on a set of rules. The electronics inside are designed to only let electricity flow under specific conditions and to protect the batteries. Some Charge Controllers also alter the voltage to optimize performance.

Battery (Energy Container)

Batteries store and contain electrical potential in the form of chemical bonds. The chemicals separate inside the battery so the positively and negatively charged molecules are stored in opposite sides of the battery. Once the molecules are reunited, an opportunity to produce electrical energy is created. There are many types of batteries with different chemistries, but they function under the same principle that the atomic bonds hold or release an electric charge.

Inverter (Energy Converter)

Inverters "invert" direct current (DC) energy into alternating current (AC).   They can also change the voltage. In Off Grid solar they invert the DC power coming from the batteries and the solar panels into AC power. Not all Off Grid energy systems need an inverter, they are only needed if some of the equipment runs on AC.

System Design

Before you can install a solar energy system you should understand first what needs power, how much daily energy it needs, and when it needs it. You must work backwards, starting with the end use, to the energy storage, and finish with the solar panels. This section will help you determine what the end use power and energy requirements are and how to best provide power for them.

First, we need a brief discussion about power and energy, since people sometimes mistakenly use the words "power" and "energy" interchangeably. Power is the **ratio** of energy per unit of time and is an *instantaneous* rate. By contrast, energy is the **amount** of power that is *generated* or *consumed* over a period of time. Also remember that solar energy systems are measured in watt-hours or kilowatt-hours. A watt-hour is *not* a ratio. It is not watts per hour, it is watt-hours. For a more detailed description of energy and power see the *Understanding Electricity Chapter* at the end of the book.

Start with Energy Efficiency

The most cost effective solar energy system is the smallest system you need. Before designing your system, first think about your energy needs. What do you really need to power? What is essential?

The last thing you want to do is design your solar energy system for out dated and inefficient equipment. For example, maybe you don't want to buy new light bulbs because you have old ones that work just fine? Why spend more money on new appliances if your current ones still work? You will quickly learn that spending money on energy efficiency is usually cheaper than buying a larger solar energy system. Investing in new LED lights or a new high efficiency refrigerator will almost always cost less than running inefficient equipment with a larger solar system. But don't take my word for it, you should do the calculations yourself.

Excerpt from *Off Grid Solar*
By Joe O'Connor

Load Calculation Table

Take an inventory of all your equipment that uses electricity that you plan to use with your solar energy system. Make a **load calculation table** which is just a spreadsheet listing the appliance running wattage, average daily hours of use, and if it is essential. The wattage is typically listed on the nameplate of the appliance along with the serial number and product specifications. If you cannot figure out the wattage then use a kill-a-watt meter to measure the running wattage. Here is an example of a load calculation table.

Appliance	**Running Wattage (W)**	**AVG Daily Usage (hours)**	**Total Energy Watt-hours (Wh)**	**Essential?**
4 LED lights	$20w \times 4 = 80$	6	480	Y
Charging for 2 Cell phones	$10w \times 2 = 20$	2	40	Y
Fan	100	4	400	Y
LCD TV	*150*	*2*	*300*	*N*
Essentials	$80 + 20 + 100 =$ **200w**		$480 + 40 + 400 = 920$	
Nonessentials	150		300	
TOTAL	350		**1220 Wh**	

Peak Power Load = 200 watts
Daily Energy Usage = 1,220 watt-hours

These are the two important values you must gain from the load calculation table. The **peak power load** is considering that only the essential loads could function at the same time. The **daily energy usage** is the energy usage under normal conditions.

Peak Power

The above load calculation table is used to add up the running wattage of all the essential equipment that could run at the same time. The most power you may need at any given time is called the **peak power load** of your system. You may determine that all your loads are essential, but in some cases you can take some equipment off the essential list. Find the running wattage of all your devices and determine under which circumstances the most power will be used at any moment.

In the example above, 200 watts is the peak load, so you would need to purchase an inverter with a capacity of at least 200 watts if you only use your TV when your lights and fan are off. It would be pretty easy to turn off the nonessential equipment and you could save on your equipment costs.

Start-up or Surge Power

Sometimes appliances have a start-up or surge wattage that is larger than the running wattage. It is also called inrush current when electrical equipment is first turned on a large current flows that exceeds the steady-state running current. Appliances with power converters, motors, and transformers all have in rush current. All motors create a spike in power in the first few seconds as the motor accelerates, then it reduces to the running wattage once it has reached a steady speed. There are many types of motors all with different levels of inrush current. Larger motors have a defined inrush current that can be calculated based on its code letter shown on its nameplate. The surge power can be three or four times the running wattage, so keep this in mind if you plan to use any large motors or equipment that uses motors. Camera flashes have large capacitors with a large inrush current. Surge Power cannot be measured with a regular multimeter or a kill-a-watt meter. However, some clamp meter have an inrush current setting that can measure peak current.

If you are using equipment that has a significant surge you should add a column to the load calculation table. Determine the one appliance that has the largest surge. Then add up all of the wattages of the essential loads and add only the largest surge wattage. This is the peak power load with surge. Inverters usually have a peak surge capacity that is larger than its running capacity, so you will need to determine if the inverter you are using will work with your equipment's running wattage and its surge wattage.

Excerpt from *Off Grid Solar*

By Joe O'Connor

Using the example above, let's assume you add a water pump and it has a surge of 1500 watts. The load calculation table would look like this:

Appliance	Running Wattage (W)	Surge Wattage (W)	AVG Daily Usage (hours)	Total Energy Watt-hours (Wh)	Essential?
4 LED lights	$20w \times 4 = 80$	-	6	480	Y
Charging for 2 Cell phones	$10w \times 2 = 20$	-	2	40	Y
Fan	*100*	200	*4*	*400*	*N*
LCD TV	*150*	-	*2*	*300*	*N*
Water Pump	500	**1500**	0.5	250	Y
Essentials	$80 + 20 + 500 =$ **600w**	$80 + 20 + 1500 =$ **1600w**		$480 + 40 + 250 = 770$	
Nonessentials	250			700	
TOTAL	850			**1470 Wh**	

Peak Power Load (Continuous) = 600 watts
Peak Power Load (Surge) = 1,600 watts
Daily Energy Usage = 1,470 watt-hours

By adding the pump, the Daily Energy Usage is only slightly higher, so this system could use the same battery capacity as the first example. But the **Peak Power Surge** increased significantly, so it will need an inverter that is capable of handling a 1,600 watt surge. It is helpful to note both the **Peak Power Continuous** and **Peak Power Surge**, because most inverters have a continuous and surge power rating. Making a load calculation table is important because the most cost effective Off Grid energy system is designed and optimized for it's load profile.

Phantom Power

Some products like televisions and cell phone chargers use energy when they are plugged in but are turned off, sometimes this is called standby power, phantom power, or vampire power. They use a little bit of energy to power internal electronics such as an internal clock. It may seem insignificant but a few watts will add up quickly if you keep it plugged in 24 hours a day every day. For example if you use a TV for an hour per day and it uses 150 watts when it's on and 5 watts when its off. Then you will use 150w * 1hr = 150Wh when it's on and 5w *23hr = 115Wh when it is off. That means almost half of the energy consumed is when it is off!

I recommend you use a surge protector with an on/off switch to completely turn off equipment with phantom power. Otherwise, you should plan on manually unplugging equipment with phantom power or account for the phantom power as another row in the load calculation table.

Daily Energy Requirements

Some equipment like a refrigerator requires power 24 hours a day, while others like a toaster might only be on for a few minutes a day. If you don't use some of the equipment everyday then take the daily average over a week. In some cases you might want to err on the safe side and over estimate. For example, in the winter you might use your lights for a longer period of time than in the summer.

Days of Autonomy

Now that you know the average daily energy requirements, you might want to size your battery capacity for more than just one day's worth of energy needs. Days of Autonomy are defined by the number of days the fully charged batteries can meet the system load requirements without recharging. Solar energy can decrease significantly in the winter months and cloud cover might reduce your energy production enough that your batteries may not get fully charged after a full day. If you have a secondary energy source like wind, hydro, or a backup generator then maybe you don't need more than a 1-2 days of autonomy. But if you are Off Grid with no other energy source, then you might want up to 3 days of autonomy. We will discuss this further in the Batteries section of the Equipment Selection chapter.

About the Author

Joe O'Connor is a solar manufacturing entrepreneur and a consultant, speaker, and writer on solar energy. With over ten years of product design and engineering experience, Joe works in the renewable energy industry in San Francisco and New York City.

Mr. O'Connor's consulting background includes solar system design, energy efficiency, and product development. He built solar energy systems in the U.S., Haiti, Nepal, Portugal, Guatemala, and Democratic Republic of the Congo. By focusing his career on the evolving trends in the solar industry, Mr. O'Connor integrates the most appropriate technologies for the best energy system.

Mr. O'Connor is a Product Development Engineer at SolarCity and a technical advisor for GivePower Foundation. He holds a B.S. from California Polytechnic University, San Luis Obispo and an M.S. from New York University, and was selected as a recipient of the Catherine B. Reynolds Foundation Fellowship for Social Entrepreneurship.

For more details please visit

www.oconenergy.com