Solar Power 101

A Practical Guide to Solar Power System Design

For Homeowners

Version 08.08.12

Compiled, edited, & updated by Vince Lombardi,
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A compilation and update of free solar design/build resources from www.freesunpower.com and other on-line/ free information sources.

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Basic Tutorials: System Overview

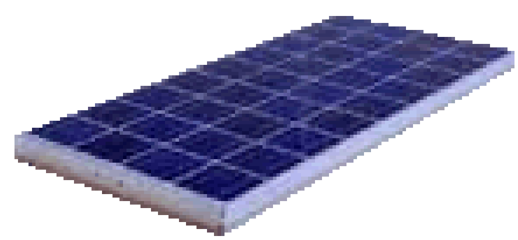
(compiled and updated by Vince Lombardi with great effort from http://www.freesunpower.com/)

This handbook is intended to be fully self-contained, without the need to go to any web resources, click on any links, or require any additional outside information beyond this printed guidebook.

A Solar Energy System is sometimes referred to as an Alternative Energy System. And while that's true, wind, geothermal, and hydro systems are also alternative energy sources. We focus primarily on Solar and will therefore simply use the phrase Solar Energy System or Solar Power System. To the left are the basic components required to produce electricity from the sun.

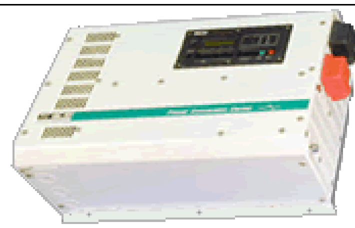
You will need one or more Solar Panels, a Charger Controller, a Power Inverter, and of course, Batteries. A brief explanation on each follows. After you get an idea of the components you'll need for your solar energy system, be sure to check out the interactive Design Tools at www.freesunpower.com to calculate how many solar panels and storage batteries you will need, determine battery bank wiring, and calculate proper wire sizes.

The first component needed is one or more Solar Panels. They supply the electricity and charge the batteries. A very small system could get away with a couple 240 watt panels but figure at least 4 to 8 for a small to medium system.



A Charge Controller is needed to prevent overcharging of the batteries. Proper charging will prevent damage and increase the life and performance of the batteries.

The Power Inverter is the heart of the system. It makes 120 volts AC from the 12 volts DC stored in the batteries. It can also charge the batteries if connected to a generator or the AC line.



Lightning Strikes can cause great damage to your solar power system and can be mitigated using Surge Arrestors in the design loop. Surge arrestors act like "clamps" in most cases. They go across the live wires with another wire going to ground. Normally they just sit there, but if the voltage goes above a certain level, they start to conduct, shorting the higher voltage to ground.

Last are the storage Batteries. They store the electrical power in the form of a chemical reaction. Without storage you would only have power when the sun was shining or the generator was running.

Summary: To summarize, there are four basic components: the Solar Panels, a Charge Controller, a Power Inverter, Surge Arrestors, and the Storage Batteries. You will of course need the proper wires & cables to connect everything and a meter to keep an eye on things would be nice. Depending on system size, costs vary widely from as little as $1,500 to $50,000 or more. Much more information is available in the remaining tutorials.

This small energy efficient home uses six 80 watt solar panels, a Xantrex 60 amp charge controller, a Xantrex 2500 watt true sine wave inverter and fifteen 105 AmpHour batteries.

Basic Tutorials: Energy Audits

Step One in sizing your solar power system:

A Report Card for Your Home

Energy Audit professionals use specialized instruments to conduct home energy audits, thoroughly testing and measuring household appliances, heating and cooling systems and building construction. They enter this data into proprietary software tools to holistically assess energy consumption.

A home energy audit includes a variety of techniques and analysis, including

- Blower door test to measure air leakage in the building envelope
- Duct blaster test to measure air leakage in the forced-air distribution system
- Assessment of insulation, windows, doors and other components of the building shell
- Evaluation of mechanical equipment, including appliances, water heating, pumps and a furnace combustion test
- For solar energy customers, the home energy audit and evaluation allows Solar Power System Designers to better customize your design providing a higher quality solar power system based on your home's specific energy needs.

Table 4-1

Typical Wattage Requirements for Common Appliances

*These ratings are only estimates

General household:

Air conditioner (room)	1,000
Air conditioner (central)	3,500
Alarm/security system	3
Blow dryer	1,000
Ceiling fan	10-50
Vacuum (upright)	800
Clock radio	2
Clothes washer	1,450
Dryer (electric)	4,000
Dryer (gas)	300
Electric blanket	200
Electric clock	2
Furnace fan	500
Garage door opener	350
Heater (portable)	1,500
Iron (electric)	1,200
Radio/phone transmit	40-150
Sewing machine	100
Table fan	10-25

Refrigeration:

Energy Star fridge/freezer 16 ft^3 (10 hrs/day)	110
Refrigerator/freezer 16 ft^3 (13 hrs/day)	475
Sun Frost refrigerator 16 ft^3 (7 hrs/day)	112
Vestfrost fridge/freezer 10.5 ft^3	60
Standard freezer 14 ft^3 (15 hrs/day)	440
Sun frost freezer 19 ft^3 (10 hrs/day)	112

Kitchen appliances:

Blender	300
Can opener (electric)	100
Coffee grinder	100
Coffee maker	800
Dishwasher	1,500
Exhaust fans (3)	144
Food dehydrator	600
Food processor	500
Microwave (.5 ft3)	750
Microwave (.8 to 1.5 ft3)	1,400
Mixer	120
Popcorn popper	250
Range (large burner)	2,100
Range (small burner)	1,250
Trash compactor	1,500
Toaster	800-1,500

Lighting:

Incandescent (100W)	100
Incandescent light (60W)	60
Compact fluorescent (60W equivalent)	16
Incandescent (40W)	40
Compact fluorescent (40W equivalent)	11

Water Pumping:

AC jet pump (¼hp) 165 gal per day, 20 ft. well	500
DC pump for house pressure system (1-2 hrs/day)	60
DC submersible pump (6 hrs/day)	50

Entertainment:

CB radio	10
CD player	35
Cell phone	24
Cell phone charger	6-20
Radio telephone	10
Satellite system (12 ft dish)	45
Stereo	25-50
TV (19-inch color)	60
TV (25-inch color)	130
TV (32-inch color)	300
VCR	20-50
DVD	11

Tools:

Band saw (14")	1,100
Chain saw (12")	1,100
Circular saw (7 ¼")	1,400
Disc sander (9")	1,200
Drill (¼")	300
Drill (½")	600
Drill (1")	1,000
Electric mower	1,500
Weed eater	500

Office:

Computer (desktop)	80-450
Computer (laptop)	20-140
Printer (ink jet)	50-75
Printer (laser)	600-1,200
Fax (stand-by)	15-45
Fax (printing)	120-350

Load Estimation Worksheet

Individual Loads	Qty X	Volts X	Amps =	Watts AC	Watts DC X	Use hrs/day X	Use days/wk ÷	7 days =	Watt Hours AC	Watt Hours DC
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AC Total Connected Watts: _____

AC Average Daily Load: _____

DC Total Connected Watts: _____

DC Average Daily Load: _____

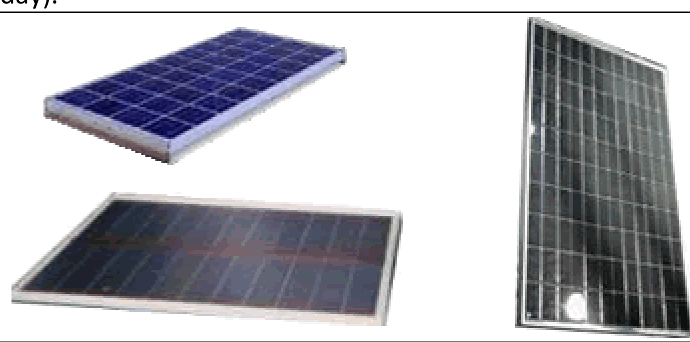
Basic Tutorials: Solar Panels

Solar Panels : An eco-friendly electric generator.

Solar panels generate free power from the sun by converting sunlight to electricity with no moving parts, zero emissions, and no maintenance. The solar panel, the first component of a electric solar power system, is a collection of individual silicon cells that generate electricity from sunlight. The photons (light particles) produce an electrical current as they strike the surface of the thin silicon wafers.

A single solar cell produces only about 1/2 (.5) of a volt. However, a typical 12 volt panel about 25 inches by 54 inches will contain 36 cells wired in series to produce about 17 volts peak output. If the solar panel can be configured for 24 volt output, there will be 72 cells so the two 12 volt groups of 36 each can be wired in series, usually with a jumper, allowing the solar panel to output 24 volts. When under load (charging batteries for example), this voltage drops to 12 to 14 volts (for a 12 volt configuration) resulting in 75 to 100 watts for a panel of this size.

Multiple solar panels can be wired in parallel to increase current capacity (more power) and wired in series to increase voltage for 24, 48, or even higher voltage systems. The advantage of using a higher voltage output at the solar panels is that smaller wire sizes can be used to transfer the electric power from the solar panel array to the charge controller & batteries. Since copper has gone up considerably in the last few years, purchasing large copper wiring and cables is quite expensive. (that's why pennies are made of mostly zinc today).



The 3 basic types of Solar Panels

Monocrystalline solar panels : The most efficient (15 – 20%) and expensive solar panels are made with Monocrystalline cells. These solar cells use very pure silicon and involve a complicated crystal growth process. Long silicon rods are produced which are cut into slices of .2 to .4 mm thick discs or wafers which are then processed into individual cells that are wired together in the solar panel.

Polycrystalline solar panels : Often called Multi-crystalline, solar panels made with Polycrystalline cells are a little less expensive & slightly less efficient than Monocrystalline cells because the cells are not grown in single crystals but in a large block of many crystals. This is what gives them that striking shattered glass appearance. Like Monocrystalline cells, they are also then sliced into wafers to produce the individual cells that make up the solar panel.

Amorphous solar panels : These are not really crystals, but a thin layer of silicon deposited on a base material such as metal or glass to create the solar panel. These Amorphous solar panels are much cheaper, but their energy efficiency is also much less so more square footage is required to produce the same amount of power as the Monocrystalline or Polycrystalline type of solar panel. Amorphous solar panels can even be made into long sheets of roofing material to cover large areas of a south facing roof surface.

Shading & Shadows on solar panels

When deciding on a location for your solar panels, make sure no shadows will fall on the solar panel array during peak sunlight hours (say, 9am to 4pm). Not only could shading of the solar panels significantly reduce their output, but also could cause damage. Many solar panel manufacturers advertise panels that can withstand shading but they use internal diodes (by-pass diodes) which in themselves reduce the power somewhat. Best to choose a good location to start with, even if it means cutting down a few trees or otherwise removing obstacles.

Temperature & Wind loading considerations

As previously discussed, you want to mount solar panels in a sunny and non-shaded location to get maximum sun. But, heat build-up is also a problem. Because the efficiency of solar panels decreases as temperature increases, the solar panel mounting system should allow for spacing around the individual solar panels for air circulation. The idea is to allow air cooling in the hot sun to reduce the temperature of the solar panels. Another consideration is wind loading. By allowing air to flow around the solar panels, not only will they remain cooler, but also the wind resistance of the entire array is less.

Types of Solar Panel Array Mountings : Fixed, Adjustable, & Tracking

Fixed Solar Panel Mounts: If you use the most simple and least expensive type of solar panel mounting system, it will be completely stationary. The solar panels should always face the equator. (due south in the northern hemisphere). Don't forget that true south varies from magnetic south. This can make a huge difference. For example, true south in eastern Washington state is 161 on a compass instead of 180. The angle of inclination (tilt) in degrees should be set to about your latitude. Slightly more than your latitude will favor the winter sun and slightly less will favor the summer sun. (for a seasonal cabin for example).

Adjustable solar panel mounts : The angle of inclination (tilt) of an adjustable solar panel mount can be changed 2 or more times during the year to account for the lower angle of the sun in winter as the earth orbits the sun causing seasonal change. A good rule of thumb is latitude + 15 degrees in the winter and latitude - 15 degrees in the summer. This will increase overall solar panel output by approximately 25%. I adjust my solar panel array 4 times per year. (Shown here in its summer position). An easy approach that works pretty good is to set the tilt for the winter position in about mid October and back to summer position in mid March.	

Tracking solar panel mounts : Tracking solar panel mounts follow the path of the sun during the day to maximize the solar radiation that the solar panels receive. A single axis tracker tracks the sun east to west and a two-axis tracker tracks the daily east to west movement of the sun and the seasonal declination movement of the sun.

I must admit that a tracking type of solar panel mount is the most efficient type. However, when I investigated the cost for these mounting systems, I found that for the 20 to 30 percent gain in output they provided I could buy 25% more panels cheaper and have the same increase in power with no mechanical failures to worry about. Also, you'll get far less extra gain in winter assuming it doesn't freeze up!

Therefore, I recommend that instead of 6 panels on a tracking mount that costs $2000-$3000, just spend $700-$800 on 2 more solar panels and gain a year round increase of 25 to 30%. Simple math, huh?

How much sunshine will I need?

For more detailed information on how many solar panels you will need based on the amount of sunshine available daily in your area (of the United States) please check out the Solar Radiation chart in Appendix C. This will give you a better idea of how many solar panels you will need for your solar power system.

Cost and expected Life-Span of solar panels

At today's prices a single solar panel, rated at 250 watts sells for about $350-$425 depending on brand. I have found that the brand does not seem to be a huge factor. If your system uses many of these panels, this would seem to be a big investment. The good news is that today's solar panels have a life expectancy of 25 to 30 years or more. And just think, they'll be making FREE electricity that whole time!

Summary

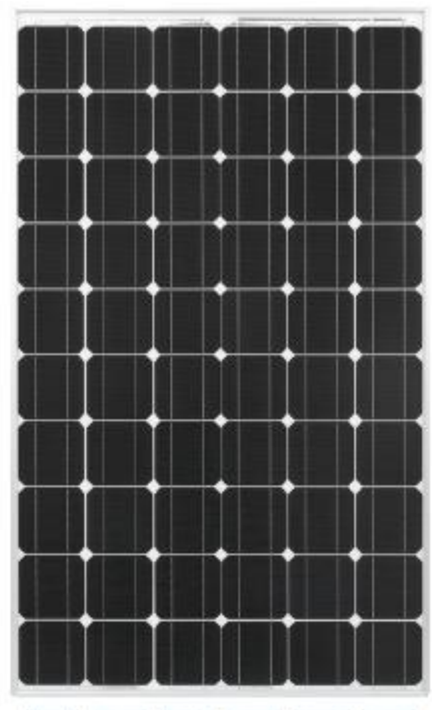
With a total of only six 240 Watt solar panels this Solar Home runs a refrigerator, computer, 27 inch color tv, microwave, various lights, misc devices, and even an Air Conditioner in the summer. Only for about 2 to 3 months in the winter (at 45 degrees north) is a generator used for 45 to 60 minutes per day to bulk charge the batteries. Since some winter days are sunny, the generator is not used every day.

Technical Specs for a Schott Mono-250 Watt Solar Panel

Model: Perform Mono 250
Brand: Schott Solar
Product Type: **Solar Panels**

Made in the USA

Item:	Price:
1202401	$365.00 Qty: 1 add to cart



With a proven field performance, Schott's Perform™ Mono 250-watt solar panel is appropriate for residential, commercial or utility scale solar power applications -- large or small. This particular solar panel is made of monocrystalline solar cells, the solar panel's first generation solar technology.

The Perform Mono 250 is manufactured in the US, in their facility in Albuquerque, New Mexico, and qualifies for:

Model	Watts	Amps	Volts	Size LxW (Inches)	Weight (lbs.)	Item
Per from Mono 250	250	8.0	31.1	66.34 X 39.09 x 1.97	41.5	1202401

Technical Data Data at Standard Test Conditions (STC)	
Module type	250
Nominal power [Wp] † Pmpp	≥ 250

Voltage at nominal power [V] Vmpp	31.1
Current at nominal power [A] Impp	8.0
Open-circuit voltage [V] Voc	37.3
Short-circuit current [A] Isc	8.5
Module Efficiency [%] η	14.9
STC (1,000 W/m2, AM 1.5 cell temperature 25ºC)Power sorting tolerance (as measured by flasher): -0 Watts / +4.99 Watts	

Data at Normal Operating Cell Temperature (NOCT)	
Nominal power [Wp] Pmpp	178.3
Voltage at nominal power [V] Vmpp	27.7
Open-circuit voltage [V] Voc	33.7
Current at nominal power [A] Impp	6.4
Temperature [ºC] TNOCT	48
NOCT (800 W/m2, AM 1.5, wind speed 1 m/s, ambient temperature 20ºC)	

Data at Low Irradiation
At a low irradiation intensity of 200 W/m^2 (AM 1.5 and cell temperature 25ºC) 96% of the STC module efficiency (1000 W/m^2) will be achieved.

Temperature Coefficients	
Power [%/ºC]	-0.44
Open-circuit voltage [%/ºC]	-0.33
Short circuit current [%/ºC]	+0.03

Mounting System Types

12.1 Mounting System Types

The photovoltaic system designer must consider many factors when selecting an appropriate site for mounting modules. The location must be oriented toward the sun and be free of shading obstacles throughout the sun's daily and seasonal paths. The site must be in proximity to the power-conditioning center to minimize line losses. The owners or operators of the system should be pleased with the aesthetics of the array and where it is located. Depending on the locale, the site may also need to provide protection from theft and vandalism. Finally, operators and designers should have easy access to perform routine maintenance.

Once you have chosen the site, you can determine the type of mounting system best suited for the site and the system application. There are various systems available for mounting a PV array, from simple bracket systems to complex dual axis trackers. The type of mounting system you choose will depend on the following factors:

- Orientation of the house.
- Shading at the site.
- Weather considerations.
- Roof material.
- Soil and/or roof load bearing capacity .
- System applications.

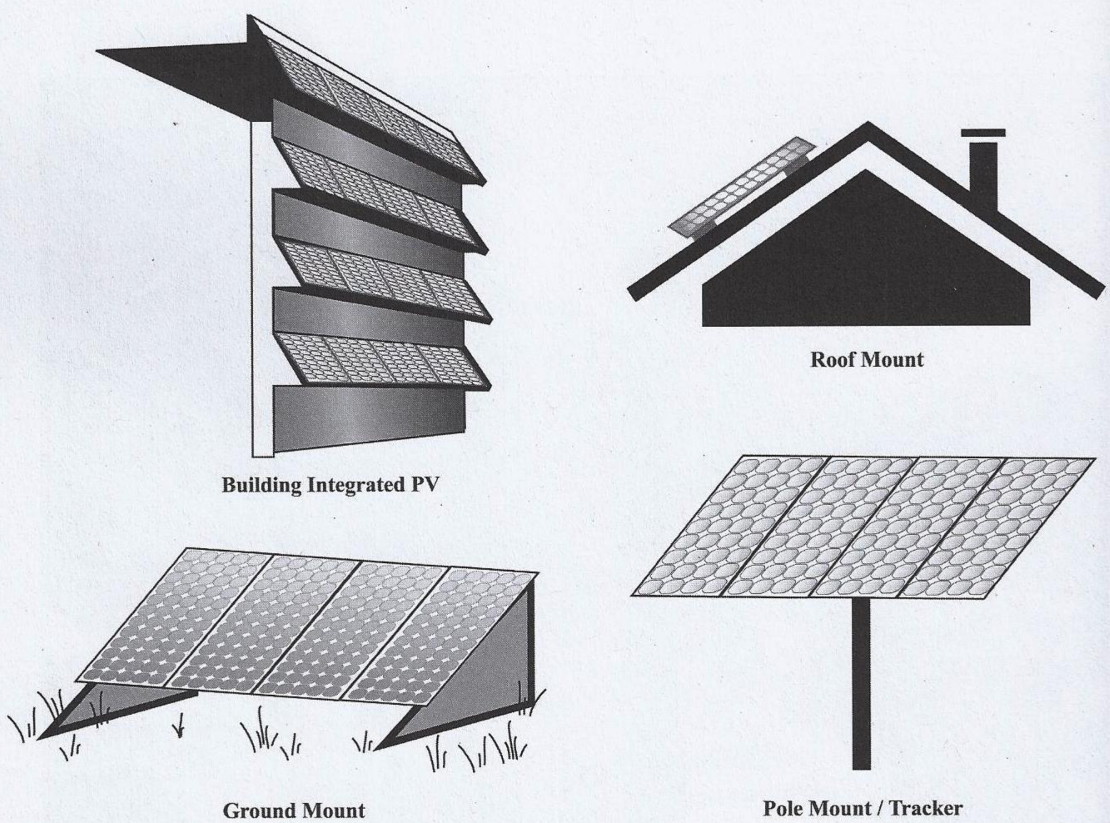


Figure 12-1
BASIC MOUNTING STRATEGIES

Basic Tutorials: Charge Controllers

Why a Charge Controller is necessary

Since the brighter the sunlight, the more voltage the solar cells produce, the excessive voltage could damage the batteries. A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array rises, the charge controller regulates the charge to the batteries preventing any over charging.

Modern multi-stage charge controllers

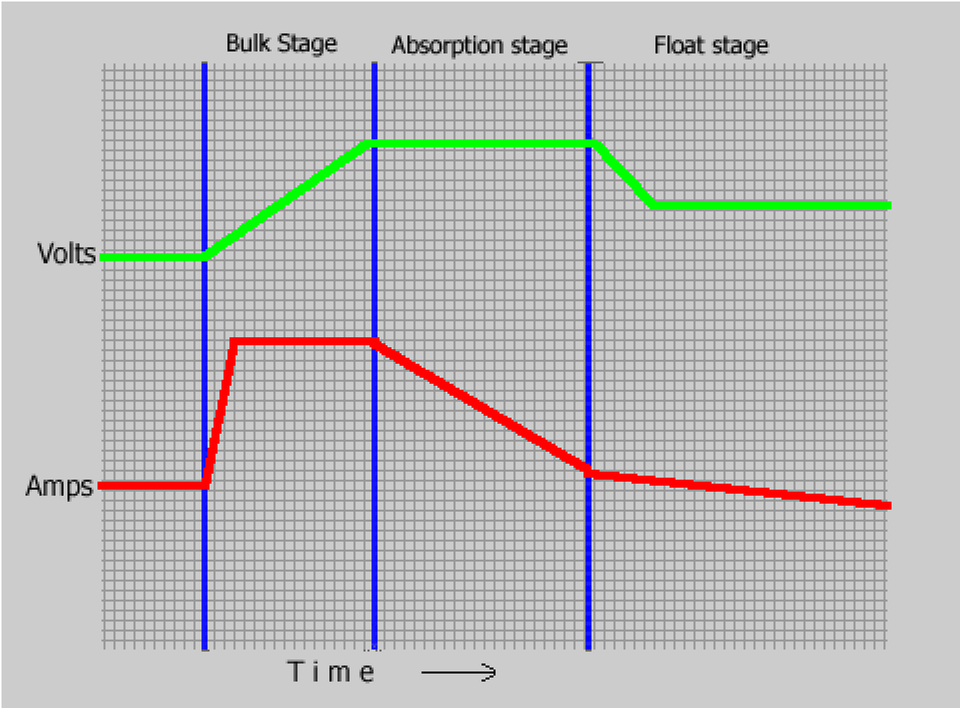
Most quality charge controller units have what is known as a 3 stage charge cycle that goes like this :

1) **BULK :** During the Bulk phase of the charge cycle, the voltage gradually rises to the Bulk level (usually 14.4 to 14.6 volts) while the batteries draw maximum current. When Bulk level voltage is reached the absorption stage begins.

2) **ABSORPTION :** During this phase the voltage is maintained at Bulk voltage level for a specified time (usually an hour) while the current gradually tapers off as the batteries charge up.

3) **FLOAT :** After the absorption time passes the voltage is lowered to float level (usually 13.4 to 13.7 volts) and the batteries draw a small maintenance current until the next cycle.

The relationship between the current and the voltage during the 3 phases of the charge cycle can be shown visually by the graph below.



MPPT Maximum Power Point Tracking

Most multi-stage charge controllers use Maximum Power Point Tracking (MPPT). They match the output of the solar panels to the battery voltage to insure maximum charge (amps). For example: even though your solar panel is rated at 100 watts, you won't get the full 100 watts unless the battery is at optimum voltage. The Power/Watts is always equal to Volts times Amps or P=E*I (see Ohm's law for more info). With a regular charge controller, if your batteries are low at say 12.4 volts, then your 100 watt solar panel rated at 6 amps at 16.5 volts (6 amps times 16.5 volts = 100 watts) will only charge at 6 amps times 12.4 volts or just 75 watts. You just lost 25% of your capacity! The MPPT controller compensates for the lower battery voltage by delivering closer to 8 amps into the 12.4 volt battery maintaining the full power of the 100 watt solar panel! 100 watts = 12.4 volts times 8 amps = 100 (P=E*I).

The Charge Controller is installed between the Solar Panel array and the Batteries where it automatically maintains the charge on the batteries using the 3 stage charge cycle just described. The Power Inverter can also charge the batteries if it is connected to the AC utility grid or -- in the case of a stand alone system -- your own AC Generator.

Summary

If you are using four 250 Watt Schott solar panels for example, your charge controller should be rated up to 40 amps. Even though the solar panels don't normally produce that much current, there is an 'edge of cloud effect'. Due to this phenomenon I have seen my four 6 amp panels (4*6=24) pump out over 32 amps. This is well over their rated 24 amps maximum. A good 3 stage 40 amp Charge Controller will run about $140 to $225 depending on features like LCD displays. For eight 250 watt solar panels you would need two 40 amp Charge Controllers to handle the power or you could increase your system voltage to 24 volts and still use just one 40 amp Charge Controller.

Basic Tutorials: Power Inverters

The Power Inverter

Unless you plan on using battery power directly for everything, you will need a Power Inverter. Since the majority of modern conveniences all run on 120 volts AC, the Power Inverter will be the heart of your Solar Energy System. It not only converts the low voltage DC to the 120 volts AC that runs most appliances, but also can charge the batteries if connected to the utility grid or a AC Generator as in the case of a totally independent stand-alone solar power system.

Square Wave power inverters (not so good):

This is the least expensive and least desirable type. The square wave it produces is inefficient and is hard on many types of equipment. These inverters are usually fairly inexpensive, 500 watts or less, and use an automotive cigarette lighter plug-in. Don't even consider one of these types of power inverters for a home system.

Modified Sine Wave power inverters (better):

This is probably the most popular and economical type of power inverter. It produces an AC waveform somewhere between a square wave and a pure sine wave. Modified Sine Wave inverters, sometimes called Quasi-Sine Wave inverters are not real expensive and work well in all but the most demanding applications and even most computers work well with a Modified Sine Wave inverter. However, there are exceptions. Some appliances that use motor speed controls or that use timers may not work quite right with a Modified Sine Wave inverter. And since more and more consumer products are using speed controls & timers, I would only recommend this type of inverter for smaller installations such as a camping cabin.

True Sine Wave power inverters (best):

A True Sine Wave power inverter produces the closest to a pure sine wave of all power inverters and in many cases produces cleaner power than the utility company itself. It will run practically any type of AC equipment and is also the most expensive. Many True Sine Wave power inverters are computer controlled and will automatically turn on and off as AC loads ask for service. I believe they are well worth the extra cost. I use a True Sine Wave power inverter myself and find that its automatic capabilities makes it seem more like Utility Company power. The Xantrex 2500 watt power inverter I use has a search feature and checks every couple of seconds for anything that wants AC, then it powers up automatically. You just flick on a light switch (or whatever) and it works. When you turn off the light or the refrigerator kicks off for example, the power inverter shuts down to save battery power.

While the Modified Sine Wave inverter (sometimes called a Quasi Sine Wave inverter) is nearly half the price of a True Sine Wave inverter, I would still recommend using a True Sine Wave inverter if you want to supply automatic power to a normal home using a wide variety of electrical devices. Also, most appliances run more efficiently and use less power with a True Sine Wave inverter as opposed to a Modified Sine Wave power inverter.

Grid Tie Power Inverters

If you are connected to normal Utility company power and just want to add some Free Sun Power electricity to reduce your electric bill and you do not need a totally independent system, it is possible that a Grid Tie power inverter will suit your needs. With a Grid Tie power inverter, whatever electricity that your solar panels produce will reduce the amount supplied by the utility company, in effect lowering your bill. And, if you are producing more power than you are using, you can actually **sell** the extra power back to the utility company! For this type of setup a much smaller battery bank can be installed just to cover short term outages from a few minutes to an hour or two. In fact, if you don't have frequent long term power outages and don't need back-up power, then you will not need any batteries at all. (But, really, what utility company never fails? :)

Input voltages. Should I use a 12, 24, or 48 volt inverter?

The main consideration when deciding on the input voltage (from your battery bank) of your Inverter is the distance between your solar panel array and your battery bank. The higher the voltage, the lower the current and the smaller the (expensive) cables need to be. Of course, when you decide on a system voltage, the Solar Panels, Inverter, and Battery Bank all need to use the same voltage. More detailed information on voltage & current is explained in the tutorial on Power & Watts in Appendix B.

To help decide on which voltage to use, check out our Wire Size Calculator (at www.freesunpower.com) which can tell you what size wire is needed to connect the solar panels to your equipment area. You can try all 3 different voltages to see the change that it can make in wire size.

Inverter Stacking: Using multiple inverters.

Two inverters can be installed in a configuration known as stacking that can provide more power or higher voltage. If two compatible inverters are stacked in *series* you can double the output voltage. This would be the technique to use to provide 120/240 volts AC. On the other hand, if you configure them in *parallel*, you can double your power. Two 4000 watt inverters in parallel would give you 8000 watts (8KW) of electricity.

Power Inverter considerations

The Power Inverter is connected directly to the batteries and the main AC breaker panel to supply power from the batteries to the loads (appliances). Check out Wires & Cables tutorial below for more info on the necessary wire size for installing one or use our new Wire Size Calculator (at www.freesunpower.com) .

The Power Inverter converts the low voltage DC to 120 volts AC. Power Inverters are available for use on 12, 24, or 48 volt battery bank configurations. Most Power Inverters can also charge the batteries if connected to the AC line. Alternatively, the AC line input could be your own AC Generator in the case of a stand-alone solar power system. When using a AC Generator to charge the batteries, the Power Inverter transfers the AC Generator power to the loads via a relay. This way the AC Generator not only charges the batteries but also supplies your AC power while it is running. If your Generator is at least 5000 watts, you can charge your batteries and have extra AC power at the same time.

Inverter: Maximum Power Point Tracking – the I-V Curve

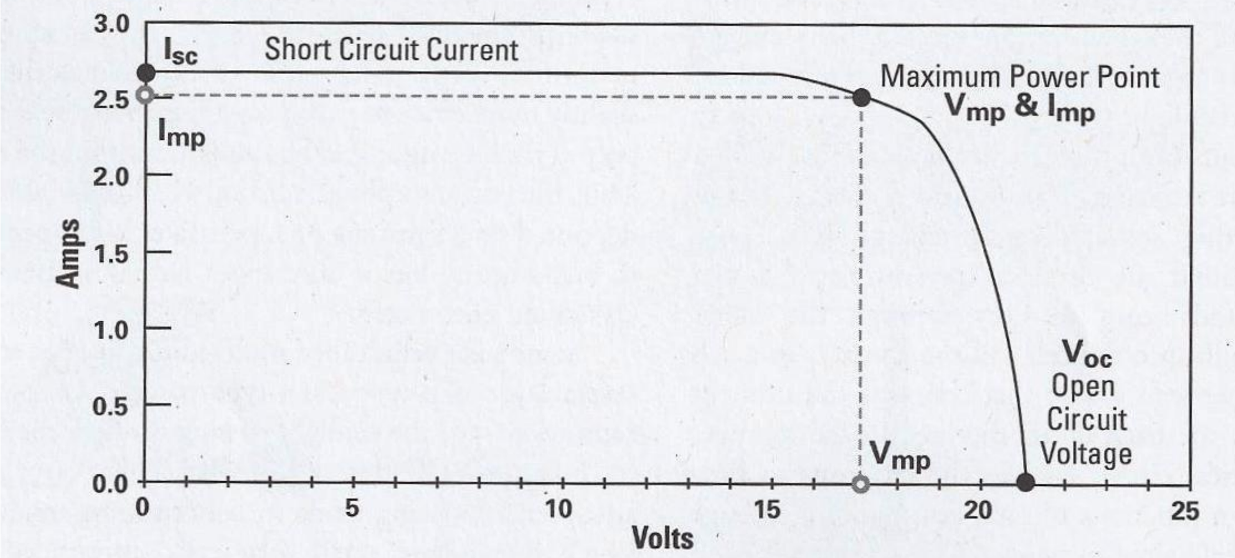


Figure 5-2

MODULE *(BRAND X)* I-V CURVE (12VDC NOMINAL)

- The point on the I-V curve, labeled V-mp and I-mp, is the operating point at which the maximum output will be produced by the module at operating conditions indicated for that curve – in other words, the V-mp and the I-mp of the module can be measured when the system is under load at 25 degrees Celsius cell temperature and 1000 Watts/square meter (Standard Testing Conditions - STC).

- Open Circuit Voltage (V-oc): the point labeled V-oc is the maximum potential voltage achieved when no current is being drawn from the module.

- Short Circuit Current (I-sc): this point, is the maximum current output that can be reached by the module under the conditions of a circuit with no resistance or a short circuit.

Outback (off-grid) Power Inverters

- OutBack Power Inverters are the standard for off-grid / stand alone systems, but they also offers grid-interactive versions of their inverter/chargers, which come in either sealed (GTFX) or vented (GVFX) models, allowing you to sell solar, wind, and/or hydro power back to the utility grid.
- Utilizing a built-in 60A transfer switch, AC power is seamlessly switched between utility and battery power. For 120/240V power output configurations, the G series can easily be combined or “stacked”, with a limit of two inverters.
- Expect to pay around $2,000 for a 3 KW (12, 24, or 48v) Outback Inverter

Enphase Grid-Tied Micro-Inverters

Enphase Micro-Inverters save you time and materials.

- One of biggest advantages to using micro-inverters is that instead of sizing (and therefore limiting) your inverter to a specific number and overall wattage of solar panels, with Enphase, you use one micro-inverter per panel.
- To increase the size of your solar electric system, you can simply add single (or any number of) panels of different wattages and even different manufacturers. You simply add one micro-inverter per panel.
- With the Enphase Micro-Inverter system, you do not have to invest in another larger inverter when you are ready to expand; just add one micro-inverter per panel.
- Expect to pay around $170 per micro-inverter.

Ease of Design and Installation

- Solar electric systems using Enphase Micro-Inverters are simple to design and simple to install:
- There are no string calculations necessary.
- Individual solar panels may be installed in any combination of module quantity, type, orientation and age.
- Each micro-inverter quickly mounts on the solar panel racking, directly beneath each panel.
- Low voltage DC wires connect from the solar panel directly to the co-located micro-inverter, eliminating the risk of the installer's exposure to lethal 600VDC power.
- Also bringing AC power directly from the panel reducing need for tedious conduit (can use standard Romex wire).
- **CANNOT** work with battery systems – need 2nd inverter - $$

How can I determine how many solar panels and batteries I'll need?

This will depend on how much electricity you are going to need and how many days you plan to be able to run on just battery power alone (no sun at all). To assist you in determining the size system you will need, our System Sizing Estimator at www.freesunpower.com , will help you calculate the number of solar panels you'll need and what size battery bank is required. We also provide a Battery Bank Designer tool to show you how to wire your battery bank for a 12, 24, or 48 volt system.

What kind of wires or cables will I need to hook all this stuff together?

The Wires & Cables tutorial below covers this question and provides a handy chart to calculate the required wire sizes based on the voltage of your system and the distances between components. Also, our new Wire Size Calculator tool will calculate wires sizes for you.

Summary

For a small system on a budget, a 2000 to 3000 watt True Sine Wave power inverter will do the job for around $1500 to $2000.   This type of inverter will run all A/C appliances and have automatic features. These higher quality Power Inverters are computer controlled and once set-up, can control your 120 volts AC, battery charging, and even auto-start compatible AC Generators; all automatically.

If your goal is to provide real home power, A True Sine Wave inverter is really your best choice. The extra cost, in the long run, is a good investment in performance and reliability. For a small seasonal use cabin, a Modified Sine Wave inverter would probably do the job.

Basic Tutorials: Storage Batteries

Storage Batteries : the fuel tank of your solar power system

Without batteries to store energy you would only have power when the sun was shining or the generator was running. This tutorial describes the 4 basic types of batteries & provides some good tips on the care & feeding of your batteries to maximize their performance and life.

1) **RV / Marine / Golf Cart** : RV or Marine type deep cycle batteries are basically for boats & campers and are suitable for only very small systems. They can be used but do not really have the capacity for continuous service with many charge/discharge cycles for many years. Regular or Car type batteries should not be used at all because they cannot be discharged very much without internal damage. A very popular battery for small systems is the Golf Cart battery. They are somewhat more expensive than deep cycle recreational batteries but are probably the least expensive choice for a small system on a budget.

Industrial Strength : Flooded, Gel, and AGM sealed batteries

The next 3 types are the heavier industrial type batteries. They are all also considered Deep Cycle and are usually Lead Acid types with much thicker internal plates that can withstand many deep discharge cycles. These next 3 are all designed for alternative energy systems.

2) **Flooded types :** These are Lead acid batteries that have caps to add water. Many manufacturers make these types for Solar Energy use. Trojan, Surrette, and Deka are probably the most well known. They are reasonably priced and work well for many years. All flooded batteries release gas when charged and should not be used indoors. If installed in an enclosure, a venting system should be used to vent out the gases which can be explosive.

3) **Gel :** Not to be confused with maintenance free batteries, sealed gel batteries have no vents and will not release gas during the charging process like flooded batteries do. Venting is therefore not required and they can be used indoors. This is a big advantage because it allows the batteries to maintain a more constant temperature and perform better.

4) **AGM :** Absorbed Glass Mat batteries are in my opinion the best available for Solar Power use. A woven glass mat is used between the plates to hold the electrolyte. They are leak/spill proof, do not out gas when charging, and have superior performance. They have all the advantages of the sealed gel types and are higher quality, maintain voltage better, self discharge slower, and last longer. The Sun Xtender series by Concorde Battery is an excellent example of AGM batteries. They are more expensive, but you usually get what you pay for. You will find this type of battery used in airplanes, hospitals, and remote telephone/cell tower installations.

Care and Feeding

As a technician (www.freesunpower.com domain owner), I used to say that if you are not comfortable, then neither is your equipment. I was mostly referring to temperature and humidity. In fact battery capacity ratings are usually specified at 77 degrees F. As batteries get colder their voltage drops and performance suffers. This is one major reason I prefer AGM batteries because they can be stored indoors where the temperatures vary less.

Another important thing to consider is how deeply you discharge your batteries. This is known as the DOD (depth of discharge). In other words, how low you let the voltage drop before the next charge cycle. Most battery ratings talk about 50% or so, but they will last longer if you keep them as charged as possible. I like the 70% range. Lead acid batteries like to be fully charged. They will last much longer if you do not discharge them too deeply. This is known as shallow cycling and greatly extends their life. However, they can withstand discharges down to 20% or so, but I wouldn't do it too often.

How to determine how charged your batteries are

Determining the percentage of battery charge from meter readings is discussed in more detail under Meters and Monitors below. A common voltmeter and this voltage chart will give you a good idea of the SOC (state of charge) of your batteries.

Wiring diagrams for multiple batteries

Another more advanced tutorial Battery Wiring Diagrams in Appendix A covers the various configurations for wiring multiple batteries together to obtain increased current capacity (power) and also different voltage configurations.

Summary

Overall, a good economical choice for a small to medium size system would probably be the Trojan L-16 flooded type batteries. I still recommend AGM if you can afford the up-front investment. For good quality batteries, you will end up paying about $115 to $160 for every 100 AmpHours of battery capacity at 12 volts.

Battery Bank Design Tool : Battery wiring made simple with just 4 clicks.

New ! Our Battery Bank Design Tool will take the confusion out of wiring up your battery bank. Use 2, 4, 6, or 12 volt batteries to build a system voltage of 12, 24, or 48 volts using series and parallel wiring with just 4 clicks. Battery bank capacities from 300 AmpHours to over 4000 AmpHours are displayed graphically so you can see exactly how to wire the batteries together.

** (Available at www.freesunpower.com) **

Basic Tutorials: AC Generators

AC Generators for back-up power and running large loads

Generators are best used for backup power during long periods of little or no sun. Under these circumstances you would run the generator just long enough to provide the batteries with their Bulk stage charge and for a portion of the Absorption charging stage. The 3 stage charge cycle is explained under Charge Controllers

The reason you would not attempt to charge the batteries fully with the generator is that towards the end of the Absorption stage, the batteries are drawing much less current and most of the generators' power is not being used. Very inefficient. This would be a good time to run your large loads (like washing machine, vacuum, etc) that would normally put a real drain on your batteries.

If you charge the batteries up to about 85% to 90% capacity this way, not only will that prevent them from being too deeply discharged, but also a small amount of winter sun could charge them the remaining 10% to 15%

Most good Power Inverters have a battery charger built in. When you run the generator and apply the AC to the inverter, it will charge the batteries and transfer the AC to your loads (appliances). This is the most efficient technique. It would be much more expensive to run a generator full time to supply power. Also, it would wear out much faster and let's not forget the noise.

This Solar Home runs a freezer, computer, 27 inch color tv, microwave, and assorted other lights and devices. In the winter I run my generator for 45 to 60 minutes per day to charge the batteries up to about 90%. Since some winter days are sunny, the generator is not used every day.

Summary

For a small to medium sized Solar Energy System, a 4000 to 7000 watt generator will work nicely. The price range is $500 to $1500 dollars depending on brand & features. You can spend much more on Auto-Start capability, diesel fueled, or propane fueled generators but I believe only large systems would make these generators economical. I bought a Generac 7000 watt model with electric start at Home Depot for $1100 and after almost 5 years of use, realize it is bigger than I needed. Still, it's nice to have the extra power.

Basic Tutorials: Wire & Cables

Correct wire sizes are essential

To connect the components of a Solar Energy System, you will need to use correct wire sizes to ensure low loss of energy and to prevent overheating and possible damage or even fire. Below is a chart showing the required wire size for wire lengths to connect the solar panels to the Charge Controller. Use these numbers for a 12 volt system to achieve a 3% or less voltage drop.

The top row represents the Wire gauge size, the left column the number of amps the solar panels are rated at, and the grid cells show the distances in feet between the Solar Panels and the Charge Controller.

For example: If you have 3 solar panels rated at 6 amps each, mounted 30 feet from the Charge Controller, then you would move down the chart to 18 amps (3 panels * 6 amps), and across to 32.5 (closest to 30), and then up the chart to #4. You would need at least #4 gauge wire (awg) to move 18 amps 30 feet with a minimum voltage drop of 3% or less, an acceptable loss.

If you can't find the exact numbers, choose either a larger gauge wire (smaller number) or select a distance longer than your actual distance.

Wire chart for connecting 12 Volt solar panels to the Charge Controller

This chart shows wire distances for a 3% voltage drop or less. These distances are calculated for a 12 volt system. Multiply distances by 2 for a 24 volt system. Multiply distances by 4 for a 48 volt system.

NOTE : This chart is an approximate distance reference and is a little conservative. For a much more accurate wire sizing, use our new Wire Size Calculator tool. It can calculate wire size using 3%, 4%, or 5% losses plus you can select 12, 24, or 48 volt systems.

	#12	#10	#8	#6	#4	#3	#2	#1	#1/0	#2/0
4	22.7	36.3	57.8	91.6	146	184	232	292	369	465
6	15.2	24.2	38.6	61.1	97.4	122	155	195	246	310
8	11.4	18.2	28.9	45.8	73.1	91.8	116	146	184	233
10	9.1	14.5	23.1	36.7	58.4	73.5	92.8	117	148	186
12	7.6	12.1	19.3	30.6	48.7	61.2	77.3	97.4	123	155
14	6.5	10.4	16.5	26.2	41.7	52.5	66.3	83.5	105	133
16	5.7	9.1	14.5	22.9	36.5	45.9	58.0	73.0	92.0	116
18	5.1	8.1	12.9	20.4	32.5	40.8	51.6	64.9	81.9	103
20	4.6	7.3	11.6	18.3	29.2	36.7	46.4	58.4	73.8	93.1
25	3.6	5.8	9.3	14.7	23.4	29.4	37.1	46.8	59.1	74.5
30	3.1	4.8	7.7	12.2	19.5	24.5	30.9	38.9	49.2	62.1
35	2.6	4.2	6.6	10.5	16.7	20.9	26.5	33.4	42.2	53.2
40	2.3	3.6	5.8	9.2	14.6	18.4	23.2	29.2	36.9	46.5

Connecting the Charge Controller

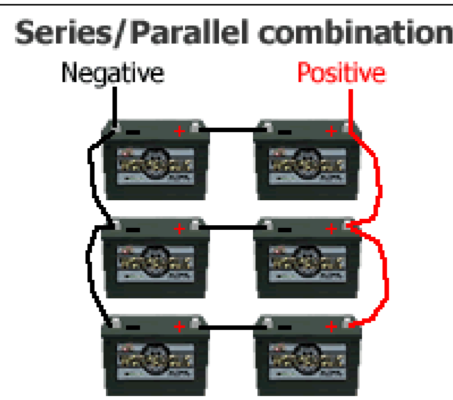
After you connect the Solar Panels to the input terminals of the Charge Controller using the above chart, you can use the same size wire to connect the Charge Controller output to the batteries since these wires will carry no more current than the solar panel wires and will probably be located pretty close to the batteries anyway.

Connecting the Power Inverter

The Power Inverter is next. Both the Power Inverter and the Batteries require the largest wires in the system. During operation, the AC produced by the Power Inverter draws considerable amps from the batteries. Not only are very large wires required, but they should not exceed 6 feet in length to reach the batteries. These wires are like the large battery cables in cars. Use the largest size possible. An AC appliance drawing 10 amps (like a microwave or vacuum cleaner) will require 100 amps at 12 volts DC. Even large cables will get warm. Don't skimp here.

Connecting the Batteries

The batteries are last. They will also require very large cables like the large battery cables in cars. The full current to the loads and also the full charging current flow thru the entire battery bank. Connect all the batteries with large high quality cables. Check out the Battery Wiring Diagrams tutorial in Appendix A for examples of Series and Parallel wiring techniques that allow the use of battery voltages of 2, 4, 6, or 12 volts. Our new Battery Bank Designer tool will show you how to connect the batteries for these various voltage systems.



Standard Romex Type Sheathed Electrical Cable for 2% voltage drop for 12, 24, and 48 volt copper wire

Table 9-5

Length (feet) of 12V Copper Wire for 2% Voltage Drop

Amps	#12	#10	#8	#6	#4	#2	#1/0	#2/0	#3/0	#4/0
1	60.6	96.8	154.2	244.4	389.6	618.6	983.6	1241.0	1566.6	1973.7
2	30.3	48.4	77.1	122.2	194.8	309.3	491.8	620.5	783.3	986.8
3	20.2	32.3	51.4	81.5	129.9	206.2	327.9	413.7	522.2	657.9
4	15.2	24.2	38.6	61.1	97.4	154.6	245.9	310.2	391.6	493.4
5	12.1	19.4	30.8	48.9	77.9	123.7	196.7	248.2	313.3	394.7
6	10.1	16.1	25.7	40.7	64.9	103.1	163.9	206.8	261.1	328.9
7	8.7	13.8	22.0	34.9	55.7	88.4	140.5	177.3	223.8	282.0
8	7.6	12.1	19.3	30.5	48.7	77.3	123.0	155.1	195.8	246.7
9	6.7	10.8	17.1	27.2	48.3	68.7	109.3	137.9	174.1	219.3
10	6.1	9.7	15.4	24.4	39.0	61.9	98.4	124.1	156.7	197.4
15	4.0	6.5	10.3	16.3	26.0	41.2	65.6	82.7	104.4	131.6
20	3.0	4.8	7.7	12.2	19.5	30.9	49.2	62.0	78.3	98.7
25	2.4	3.9	6.2	9.8	15.6	24.7	39.3	49.6	62.7	78.9
30	2.0	3.2	5.1	8.1	13.0	20.6	32.8	41.4	52.2	65.8
35	1.7	2.8	4.4	7.0	11.1	17.7	28.1	35.5	44.8	56.4
40	1.5	2.4	3.9	6.1	9.7	15.5	24.6	31.0	39.2	49.3
45	1.3	2.2	3.4	5.4	8.7	13.7	21.9	27.6	34.8	43.9
50	1.2	1.9	3.1	4.9	7.8	12.4	19.7	24.8	31.3	39.5
55	1.1	1.8	2.8	4.4	7.1	11.2	17.9	22.6	28.5	35.9
60	1.0	1.6	2.6	4.1	6.5	10.3	16.4	20.7	26.1	32.9
65	0.9	1.5	2.4	3.8	6.0	9.5	15.1	19.1	24.1	30.4
70	0.9	1.4	2.2	3.5	5.6	8.8	14.1	17.7	22.4	28.2
75	0.8	1.3	2.1	3.3	5.2	8.2	13.1	16.5	20.9	26.3
80	0.8	1.2	1.9	3.1	4.9	7.7	12.3	15.5	19.6	24.7
85	0.7	1.1	1.8	2.9	4.6	7.3	11.6	14.6	18.4	23.2
90	0.7	1.1	1.7	2.7	4.3	6.9	10.9	13.8	17.4	21.9
95	0.6	1.0	1.6	2.6	4.1	6.5	10.4	13.1	16.5	20.8
100	0.6	1.0	1.5	2.4	3.9	6.2	9.8	12.4	15.7	19.7
110	0.6	0.9	1.4	2.2	3.5	5.6	8.9	11.3	14.2	17.9
120	0.5	0.8	1.3	2.0	3.2	5.2	8.2	10.3	13.1	16.4
130	0.5	0.7	1.2	1.9	3.0	4.8	7.6	9.5	12.1	15.2
140	0.4	0.7	1.1	1.7	2.8	4.4	7.0	8.9	11.2	14.1
150	0.4	0.6	1.0	1.6	2.6	4.1	6.6	8.3	10.4	13.2
160	0.4	0.6	1.0	1.5	2.4	3.9	6.1	7.8	9.8	12.3
170	0.4	0.6	0.9	1.4	2.3	3.6	5.8	7.3	9.2	11.6
180	0.3	0.5	0.9	1.4	2.2	3.4	5.5	6.9	8.7	11.0
190	0.3	0.5	0.8	1.3	2.1	3.3	5.2	6.5	8.2	10.4
200	0.3	0.5	0.8	1.2	1.9	3.1	4.9	6.2	7.8	9.9

Values in shaded area may *not* meet NEC® requirements.

Table 9-6

Length (feet) of 24V Copper Wire for 2% Voltage Drop

Amps	#12	#10	#8	#6	#4	#2	#1/0	#2/0	#3/0	#4/0
1	121.2	193.5	308.5	488.8	779.2	1237.1	1967.2	2481.9	3133.2	3947.4
2	60.6	96.8	154.2	244.4	389.6	618.6	983.6	1241.0	1566.6	1973.7
3	40.4	64.5	102.8	162.9	259.7	412.4	655.7	827.3	1044.4	1315.8
4	30.3	48.4	77.1	122.2	194.8	309.3	491.8	620.5	783.3	986.8
5	24.2	38.7	61.7	97.8	155.8	247.4	393.4	496.4	626.6	789.5
6	20.2	32.3	51.4	81.5	129.9	206.2	327.9	413.7	522.2	657.9
7	17.3	27.6	44.1	69.8	111.3	176.7	281.0	354.6	447.6	563.9
8	15.2	24.2	38.6	61.1	97.4	154.6	245.9	310.2	391.6	493.4
9	13.5	21.5	34.3	54.3	86.6	137.5	218.6	275.8	348.1	438.6
10	12.1	19.4	30.8	48.9	77.9	123.7	196.7	248.2	313.3	394.7
15	8.1	12.9	20.6	32.6	51.9	82.5	131.1	165.5	208.9	263.2
20	6.1	9.7	15.4	24.4	39.0	61.9	98.4	124.1	156.7	197.4
25	4.8	7.7	12.3	19.6	31.2	49.5	78.7	99.3	125.3	157.9
30	4.0	6.5	10.3	16.3	26.0	41.2	65.6	82.7	104.4	131.6
35	3.5	5.5	8.8	14.0	22.3	35.3	56.2	70.9	89.5	112.8
40	3.0	4.8	7.7	12.2	19.5	30.9	49.2	62.0	78.3	98.7
45	2.7	4.3	6.9	10.9	17.3	27.5	43.7	55.2	69.6	87.7
50	2.4	3.9	6.2	9.8	15.6	24.7	39.3	49.6	62.7	78.9
55	2.2	3.5	5.6	8.9	14.2	22.5	35.8	45.1	57.0	71.8
60	2.0	3.2	5.1	8.1	13.0	20.6	32.8	41.4	52.2	65.8
65	1.9	3.0	4.7	7.5	12.0	19.0	30.3	38.2	48.2	60.7
70	1.7	2.8	4.4	7.0	11.1	17.7	28.1	35.5	44.8	56.4
75	1.6	2.6	4.1	6.5	10.4	16.5	26.2	33.1	41.8	52.6
80	1.5	2.4	3.9	6.1	9.7	15.5	24.6	31.0	39.2	49.3
85	1.4	2.3	3.6	5.8	9.2	14.6	23.1	29.2	36.9	46.4
90	1.3	2.2	3.4	5.4	8.7	13.7	21.9	27.6	34.8	43.9
95	1.3	2.0	3.2	5.1	8.2	13.0	20.7	26.1	33.0	41.6
100	1.2	1.9	3.1	4.9	7.8	12.4	19.7	24.8	31.3	39.5
110	1.1	1.8	2.8	4.4	7.1	11.2	17.9	22.6	28.5	35.9
120	1.0	1.6	2.6	4.1	6.5	10.3	16.4	20.7	26.1	32.9
130	0.9	1.5	2.4	3.8	6.0	9.5	15.1	19.1	24.1	30.4
140	0.9	1.4	2.2	3.5	5.6	8.8	14.1	17.7	22.4	28.2
150	0.8	1.3	2.1	3.3	5.2	8.2	13.1	16.5	20.9	26.3
160	0.8	1.2	1.9	3.1	4.9	7.7	12.3	15.5	19.6	24.7
170	0.7	1.1	1.8	2.9	4.6	7.3	11.6	14.6	18.4	23.2
180	0.7	1.1	1.7	2.7	4.3	6.9	10.9	13.8	17.4	21.9
190	0.6	1.0	1.6	2.6	4.1	6.5	10.4	13.1	16.5	20.8
200	0.6	1.0	1.5	2.4	3.9	6.2	9.8	12.4	15.7	19.7

Values in shaded area may *not* meet *NEC*® requirements.

Table 9-7

Length (feet) of 48V Copper Wire for 2% Voltage Drop

Amps	#12	#10	#8	#6	#4	#2	#1/0	#2/0	#3/0	#4/0
1	242.4	387.1	617.0	977.6	1558.4	2474.2	3934.4	4963.8	6266.3	7894.7
2	121.2	193.5	308.5	488.8	779.2	1237.1	1967.2	2481.9	3133.2	3947.4
3	80.8	129.0	205.7	325.9	519.5	824.7	1311.5	1654.6	2088.8	2631.6
4	60.6	96.8	154.2	244.4	389.6	618.6	983.6	1241.0	1566.6	1973.7
5	48.5	77.4	123.4	195.5	311.7	494.8	786.9	992.8	1253.3	1578.9
6	40.4	64.5	102.8	162.9	259.7	412.4	655.7	827.3	1044.4	1315.8
7	34.6	55.3	88.1	139.7	222.6	353.5	562.1	709.1	895.2	1127.8
8	30.3	48.4	77.1	122.2	194.8	309.3	491.8	620.5	783.3	986.8
9	26.9	43.0	68.6	108.6	173.2	274.9	437.2	551.5	696.3	877.2
10	24.2	38.7	61.7	97.8	155.8	247.4	393.4	496.4	626.6	789.5
15	16.2	25.8	41.1	65.2	103.9	164.9	262.3	330.9	417.8	526.3
20	12.1	19.4	30.8	48.9	77.9	123.7	196.7	248.2	313.3	394.7
25	9.7	15.5	24.7	39.1	62.3	99.0	157.4	198.6	250.7	315.8
30	8.1	12.9	20.6	32.6	51.9	82.5	131.1	165.5	208.9	263.2
35	6.9	11.1	17.6	27.9	44.5	70.7	112.4	141.8	179.0	225.6
40	6.1	9.7	15.4	24.4	39.0	61.9	98.4	124.1	156.7	197.4
45	5.4	8.6	13.7	21.7	34.6	55.0	87.4	110.3	139.3	175.4
50	4.8	7.7	12.3	19.6	31.2	49.5	78.7	99.3	125.3	157.9
55	4.4	7.0	11.2	17.8	28.3	45.0	71.5	90.3	113.9	143
60	4.0	6.5	10.3	16.3	26.0	41.2	65.6	82.7	104.4	131.6
65	3.7	6.0	9.5	15.0	24.0	38.1	60.5	76.4	96.4	121.5
70	3.5	5.5	8.8	14.0	22.3	35.3	56.2	70.9	89.5	112.8
75	3.2	5.2	8.2	13.0	20.8	33.0	52.5	66.2	83.6	105.3
80	3.0	4.8	7.7	12.2	19.5	30.9	49.2	62.0	78.3	98.7
85	2.9	4.6	7.3	11.5	18.3	29.1	46.3	58.4	73.7	92.9
90	2.7	4.3	6.9	10.9	17.3	27.5	43.7	55.2	69.6	87.7
95	2.6	4.1	6.5	10.3	16.4	26.0	41.4	52.3	66.0	83.1
100	2.4	3.9	6.2	9.8	15.6	24.7	39.3	49.6	62.7	78.9
110	2.2	3.5	5.6	8.9	14.2	22.5	35.8	45.1	57.0	71.8
120	2.0	3.2	5.1	8.1	13.0	20.6	32.8	41.4	52.2	65.8
130	1.9	3.0	4.7	7.5	12.0	19.0	30.3	38.2	48.2	60.7
140	1.7	2.8	4.4	7.0	11.1	17.7	28.1	35.5	44.8	56.4
150	1.6	2.6	4.1	6.5	10.4	16.5	26.2	33.1	41.8	52.6
160	1.5	2.4	3.9	6.1	9.7	15.5	24.6	31.0	39.2	49.3
170	1.4	2.3	3.6	5.8	9.2	14.6	23.1	29.2	36.9	46.4
180	1.3	2.2	3.4	5.4	8.7	13.7	21.9	27.6	34.8	43.9
190	1.3	2.0	3.2	5.1	8.2	13.0	20.7	26.1	33.0	41.6
200	1.2	1.9	3.1	4.9	7.8	12.4	19.7	24.8	31.3	39.5

Values in shaded area may *not* meet *NEC*® requirements.

Monitoring battery voltage and system performance

It is important to know the state of your system. Specifically, you need to keep close watch on the SOC (state of charge) of your batteries. By not allowing your batteries to discharge below a certain point you can greatly improve their performance and extend their life. Monitoring the Voltage and Current readings in your system will tell you how full your batteries are and how fast they are charging or discharging. All this can be monitored with one or more meters. I like to have one meter continously display the Solar Panels charging current and a multi-function display for Voltage, AmpHours, and other functions.

A short electronics lesson

Voltage : is the equivalent of the water pressure in a water pipe.

Current : is the equivalent of the rate of water flowing in a water pipe.

Power : is the amount of water flowing thru the pipe based on the water pressure AND the rate of flow.

Check out the Watts & Power tutorial in Appendix B for more details on voltage, current, and power.

How do I interpret all these voltage readings?

So, you can measure your battery Voltage to determine how charged they are. And you can measure the Current the see the rate of charge or discharge (how fast the batteries are gaining or losing power). Use the chart below to interpret your battery voltage readings.

This chart will allow you to get a pretty good idea of how charged the batteries are. They must not be charging or discharging for these voltages to be correct. Also, it should be at least 1 or 2 hours since they were. A good time to check is early in the morning before charging starts or any appliances are turned on. This will tell you the SOC (state of charge) or simply put, how full they are.

Battery Voltage Chart	
% of Full Charge	Voltage
100 % charged	**12.7 volts**
90 % charged	**12.6 volts**
80 % charged	**12.5 volts**
70 % charged	**12.3 volts**
60 % charged	**12.2 volts**
50 % charged	**12.1 volts**
40 % charged	**12.0 volts**
30 % charged	**11.9 volts**
20 % charged	**11.8 volts**
10 % charged	**11.7 volts**
completely discharged	**11.6 volts or less**

Remember, this measurement is most accurate after the batteries have been at rest at least 1 hour, and neither charging nor discharging.

So how much can I expect to pay for a multi-function monitor?

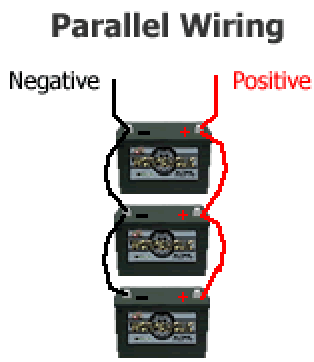
Trace (now Xantrex) makes several nice monitors and so do a number of others. Tri-Metric model 2020 is the one I chose but they all have similar functions. You can measure battery voltage, charge/discharge current, percentage of full charge, days since last full charge and many other useful functions. Expect to pay $150 to $200 for a good multi-function monitor.

Appendix A: Advanced Tutorials - Battery Wiring

Battery wiring diagrams

The following diagrams illustrate how to get increased current (more power) by using parallel wiring and how to increase voltage levels by using series wiring. You can do both using series and parallel wiring in combinations.

Use parallel wiring to increase current (power).



This diagram shows a simple parallel circuit to increase current or power. Assume that we are using 12 volt batteries. The power of all 3 batteries add to give us the effect of a battery 3 times as powerful but the voltage stays the same at 12 volts. Parallel wiring increases current but the voltage does not change. This is the wiring used when jump starting a car for example.

Use series wiring to increase voltage

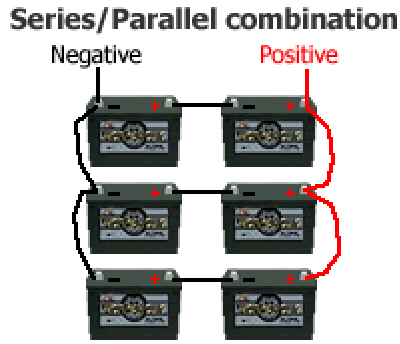
This diagram shows a simple series circuit to increase the battery voltage level. Assume that we are using really big 4 volt industrial batteries.

The voltage of all 3 batteries add to give us the effect of a battery 3 times the voltage or in this case a very large 12 volt battery. In this circuit the current is the same as the current in just 1 of the batteries. But since the 4 volt industrial batteries are very large, we have in effect created a huge 12 volt battery.

Use series & parallel wiring in combination

This diagram shows a combination series and parallel circuit to increase both the battery current and voltage level at the same time. Assume this time we are using 12 volt batteries.

The left to right series connection add the two 12 volt batteries to make 24 volts. And, since we did this 3 times and then connected each group of 2 (now 24 volts) in parallel we end up with one very large 24 volt battery. It has twice the voltage of a single 12 volt battery and 3 times the current or power because all 3 groups are wired in parallel.



The sky's the limit

So, using series wiring, you can build up the voltage to the level you need and using parallel wiring you can increase the current or power. For example, you could setup a 24 volt battery bank by connecting two 12 batteries together in series or create a 48 volt battery bank by connecting four 12 volt batteries in series. Then just repeat this until you get the power you want and put all those now 24 or 48 volt groups in parallel. Batteries for solar power systems are available in 2, 4, 6, and 12 volts, so any combination of voltage and power is possible. Try this yourself using the Battery Bank Designer with 4 easy point & click choices.

See complete circuit diagrams of example Solar Energy Systems.

These Example System Diagrams will show how to connect the components of a solar energy system. A 2 KW, 4 KW, and 8 KW system are shown and include the solar panels, combiner boxes, charge controller(s), power inverter(s), battery bank, shunt & meter circuits, AC breaker panel, and AC generator wiring.

Design your system *quickly* with our Interactive Design Tools

***(Note : These design tools require javascript to be turned on in your browser) ***

* Check out our easy point & click System Sizing Estimator to quickly & easily calculate the number of solar panels and storage batteries you'll need for a wide range of system sizes.

* Our Battery Bank Design Tool will take the confusion out of wiring up your battery bank. Use 2, 4, 6, or 12 volt batteries to build a system voltage of 12, 24, or 48 volts using series and parallel wiring with just 4 clicks. Battery bank capacities from 300 AmpHours to over 4000 AmpHours are displayed graphically so you can see exactly how to wire the batteries together.

* This Wire Size Calculator will allow you to quickly find the correct wire size in AWG (American Wire Gauge) based on the distance to your solar panel array & the amount of amperage your panels put out. No math required!

New Feature! Check out our new feature Solar Projects where you can build easy, do-it-yourself projects for your solar power system to save money and have fun doing it!

(www.freesunpower.com)

Appendix B: Advanced Tutorials -- Watts & Power

Definitions

Voltage : is the electromotive force (pressure) applied to an electrical circuit measured in volts (E).
Current : is the flow of electrons in an electrical circuit measured in amperes (I).
Resistance : is the opposition to the flow of electrons in an electrical circuit measured in ohms (R).
Power : is the product of the voltage times the current in an electrical circuit measured in watts (P).

Ohm's Law

In its simplest form, Ohm's law states that the current in an electrical circuit is directly proportional to the applied voltage and the resistance of the circuit. The 3 most common mathematical expressions are:

$$E=I*R \qquad I=E/R \qquad R=E/I$$

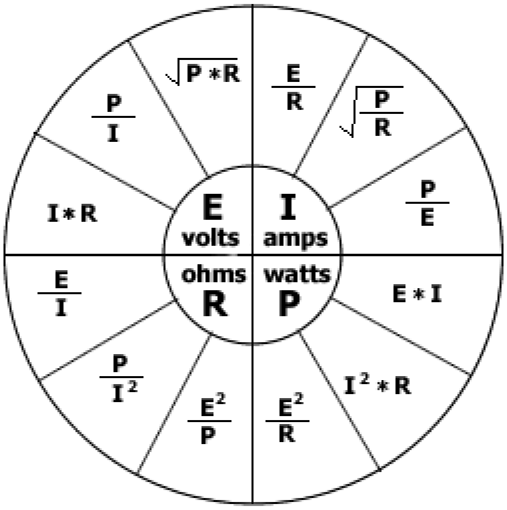
Also, the power can be expressed as $P=E*I$ and with a little algebra we can combined these expressions and derive $P=E^2 / R$

So what does all this mean? Well, for one thing it becomes clear that an appliance (load) that draws 1 amp (ampere) of current at 120 volts will draw 10 times as much current at 12 volts (1/10 the voltage) or 10 amps. Since P=E*I then 120 volts times 1 amp = 120 watts. Also, 12 volts times 10 amps = 120 watts. So you can see that the power remains the same. As the Voltage goes down, the Amperage increases to maintain the power which will be determined by the 3rd factor, resistance.

Ok, now let's say you have a nice 1200 watt hairdryer. Well, that would work out to 10 amps at 120 volts. But, when your power inverter uses the 12 volts supplied from your batteries, the amperage goes up to 100 amps to produce the same 1200 watts! (P=E*I). This means that even the very large cables connecting your batteries to the inverter will get warm. This is why it becomes impractical or impossible to run say, a 4000 watt electric clothes dryer. Even if you had large enough wires to handle the required 333 or so amps, your batteries would not last long.

It is true that the cables will not get as warm if the current can be reduced by increasing the voltage by using a 24 volt battery system or even a 48 volt battery system. This still will not change the amount of power that your batteries must supply.

The 12 basic formulas for Ohm's Law can be expressed as follows :



1. Voltage = the Square Root of Power * Resistance
2. Voltage = Power / Current
3. Voltage = Current * Resistance
4. Resistance = Voltage / Current
5. Resistance = Power / Current squared
6. Resistance = Voltage squared / Power
7. Current = Voltage / Resistance
8. Current = the Square Root of Power / Resistance
9. Current = Power / Voltage
10. Power = Voltage * Current
11. Power = the Current squared * Resistance
12. Power = the Voltage squared / Resistance

You will primarily be interested in just formula number 10 : P=E*I (watts = volts * amps). With this single formula, you can determine the wattage a device uses by multiplying the Voltage in Volts times the Current in Amps.

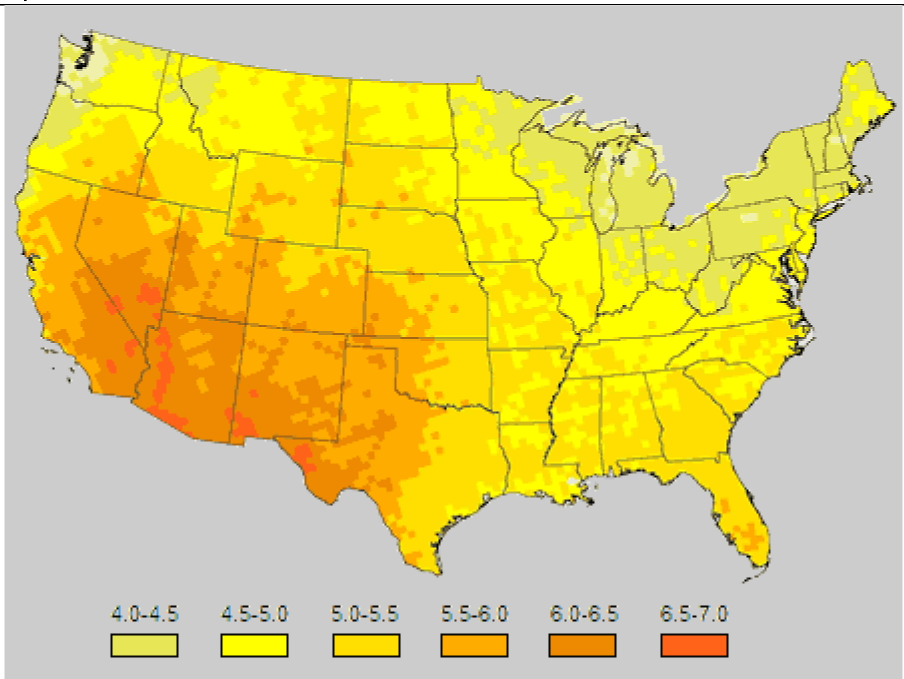
Summary

1) You will need to replace electric appliances that need large amounts of power with gas (natural or LP) or other alternatives. This would usually be anything that uses 1500 watts or more. All appliances that are UL rated will have their power consumption in watts listed on a placard or label near the AC cord.
2) When you find the wattage listing you can divide by 120 to get the number of amps the appliance will require. Multiply this number by 10 for a 12 volt system to determine the number of amps that will be drawn from the batteries. For a 24 volt system, multiply by 5. For a 48 volt system multiply by 2.5.

Appendix C: Advanced Tutorials: Solar Radiation

Solar Radiation : Sunshine across the United States:

The map below shows the yearly average of the approximate daily sunshine in KiloWattHours per square meter of flat panel surface area facing the equator and tilted at an angle equal to your latitude. *Translation: Each zone shows the average number of hours of sunshine per day.* A typical solar panel in the range of 75 to 85 watts is about a square meter. So if you have six 80 watt solar panels in the 5.0-5.5 zone you can figure 6 panels times 80 watts times 5 hours equals 2400 watthours per day or 2.4 KiloWatts per day. Of course, this is an average and you will get more power in the summer than the winter, obviously.



Another way to calculate this is using AmpHours. An 80 watt panel at 12 volts will produce about 5.5 amps under strong sunlight. If you have 5 hours of sun times 5.5 amps you will get 27.5 AmpHours per day. Using the example of 6 solar panels, that becomes 6 times 27.5 or 165 AmpHours per day.

A practical everyday example using AmpHours instead of WattHours :

Ok, you ask, how is all of this useful? Well, when calculating system size for both the number of solar panels and the number of batteries needed it is customary to use WattHours. However, in practice, when your system is operating, your meters/monitors will give you AmpHour information. For example, if your charge controller is showing that by midday you have already received 85 AmpHours of energy and the only thing running is your refrigerator (using 40 AmpHours per day), then you can quickly see that you are gaining and your batteries are charging not discharging. This is immediately obvious without having to convert everything to watts and WattHours.

Solar Pathfinder

(more info: www.solarpathfinder.com)

The Solar Pathfinder is a site assessment tool used for site shading analysis and for determining the best location for a solar array for maximum solar radiation.

Utilizing Sun Path Charts appropriate for a given latitude (see Fig. C-3), the device is set up, facing south (towards the equator in northern latitudes) and corrected for magnetic south (magnetic declination – see chart below) accordingly by rotating the Sun Path chart the appropriate corrective degrees – for Winchester, VA area – about 10 degrees west of magnetic South (east of magnetic North on the Sunpath Chart) – so we correct 10 degrees east of magnetic North on the Sunpath chart.

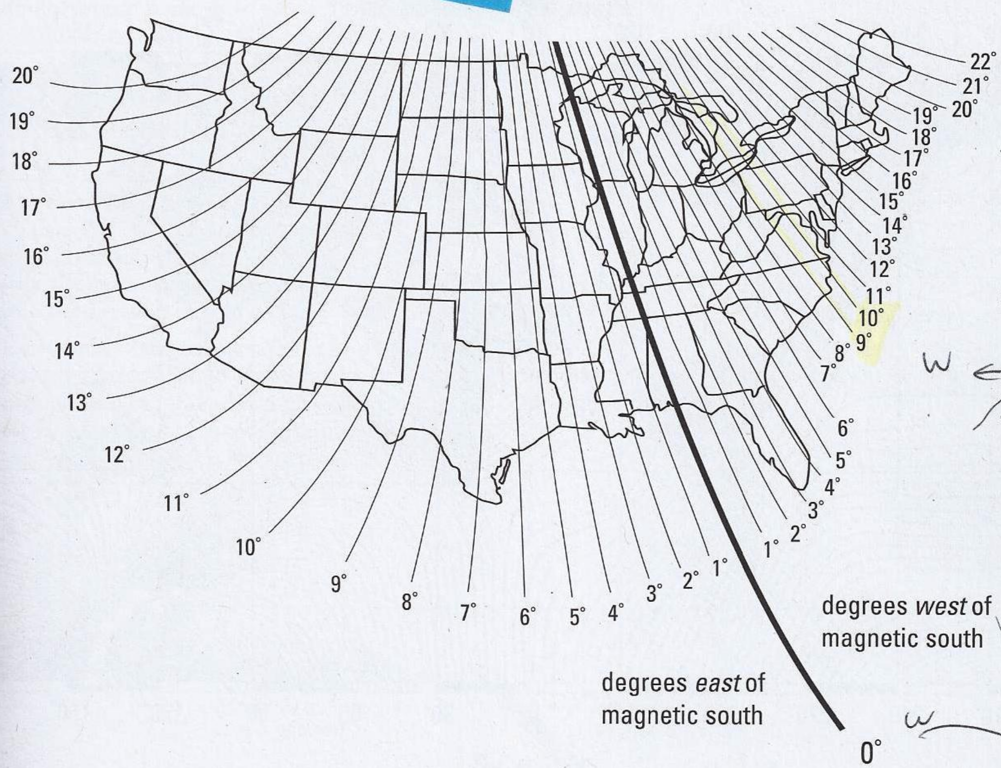
Since the latitude of Winchester is about 39 degrees, we use the Sun Path Chart for 37 to 43 degrees.

We then position the Solar Pathfinder needle South, level the device using the leveling bubble, and look straight down on the leveled, south facing unit to see where shadows from trees, buildings and other obstructions interfere with daylight during all times of day and all months of the year.

Using a special marking wax pen, we then trace the shadow pattern projected down onto the Sun Path Chart for hand analysis or we simply photograph the Sun Path Chart to be read into special Solar Pathfinder software for computer analysis.

For any given month, the numbers along a given month line total 100% -- we can add up all of the numbers manually for a given month between the shadow marks and tell just how much of our total usable sun (percentage) that we can expect for a given location. We move around taking different chart readings / shadow patterns until we find the most suitable location to locate a solar array -- or make one (i.e. cut down a tree if absolutely necessary and unavoidable).

Magnetic Declination



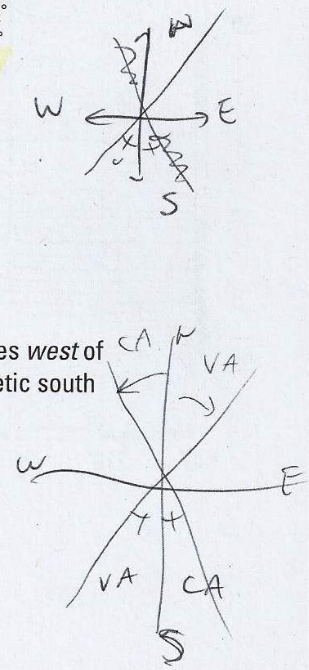


Figure 3-2

MAGNETIC DECLINATION IN THE UNITED STATES

The site's latitude (the distance north or south of the earth's equator) determines whether the sun appears to travel in the northern or southern sky. For example, Denver, Colorado, is located at approximately 40 degrees north latitude, and the sun appears to move across the southern sky. At midday, the sun is exactly true south.

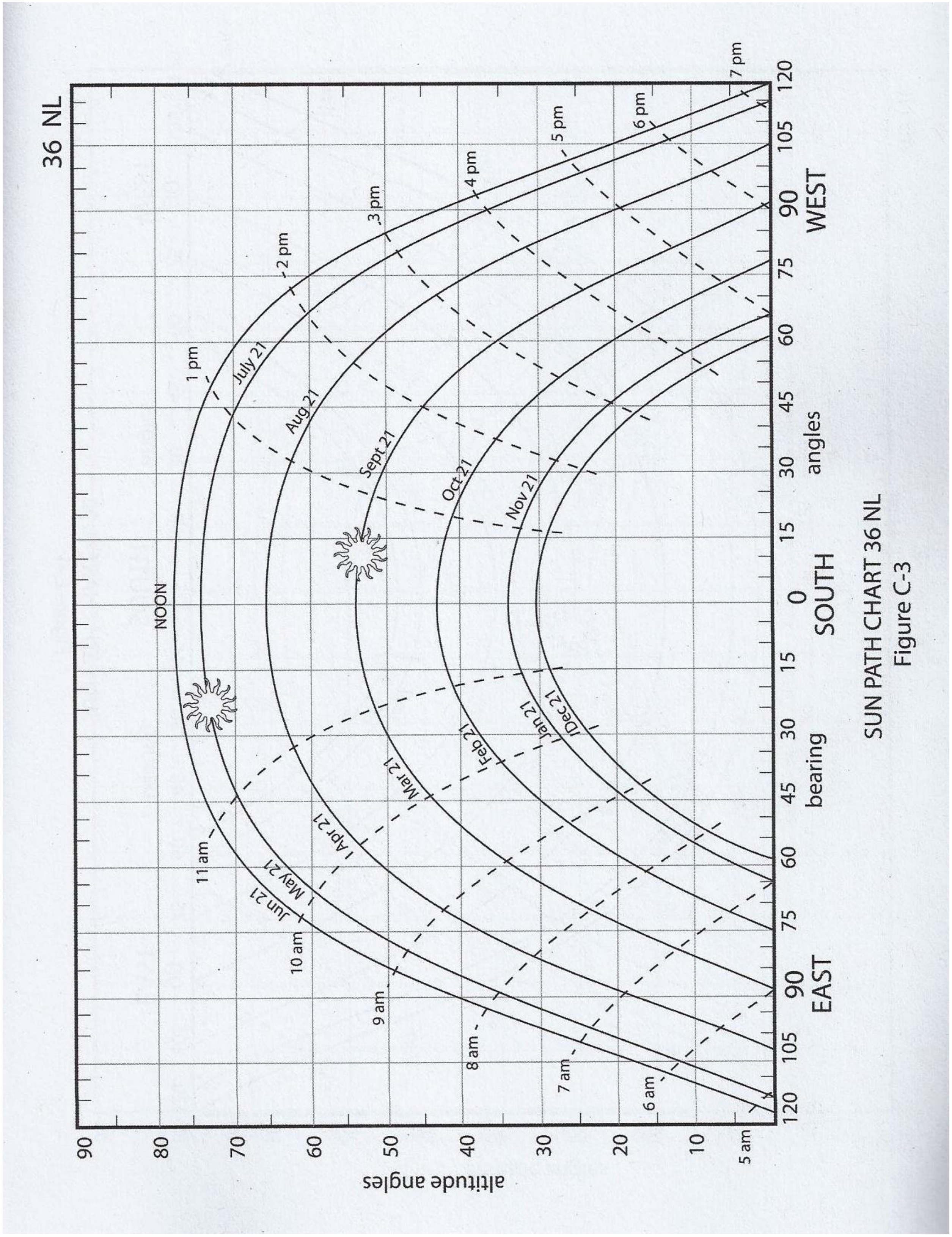
Once a day, the earth rotates on its axis, which is tilted approximately 23.5 degrees from vertical. The sun appears to rise and set at different points on the horizon throughout the year because of this tilt. On the fall and spring equinoxes (September 21 and March 21) the sun appears to rise exactly due east of south and appears to set exactly due west of south. During the winter months, the sun appears to rise south of true east and set south of true west; in the summer months, it appears to rise north of true east and set north of true west. Figure 3-1 illustrates the solar position at different times of day and year.

Orientation

The sun's apparent location east and west of true south is called **azimuth**, which is measured in degrees east or west of true south. See Figure 3-4. Since there are 360 degrees in a circle and 24 hours in a day, the sun appears to move 15 degrees in azimuth each hour (360 degrees divided by 24 hours). Magnetic south or south on a compass is not the same as true south. A compass aligns with the earth's magnetic field, which is not necessarily aligned with the earth's rotational axis. The deviation of magnetic south from true south is called magnetic declination. Refer to a map or ask a local surveyor for your location's **magnetic declination**. Figures 3-2 and 3-3 provide approximate magnetic declination for the United States and the world respectively. These maps are sufficient for our purposes.

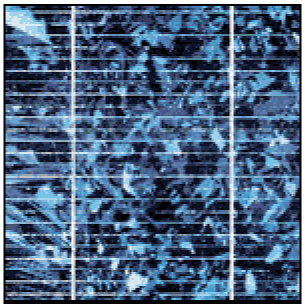
Daily performance will be optimized if fixed mounted collectors are faced true south or 0 degrees

Solar Pathfinder Sunpath Chart(s):

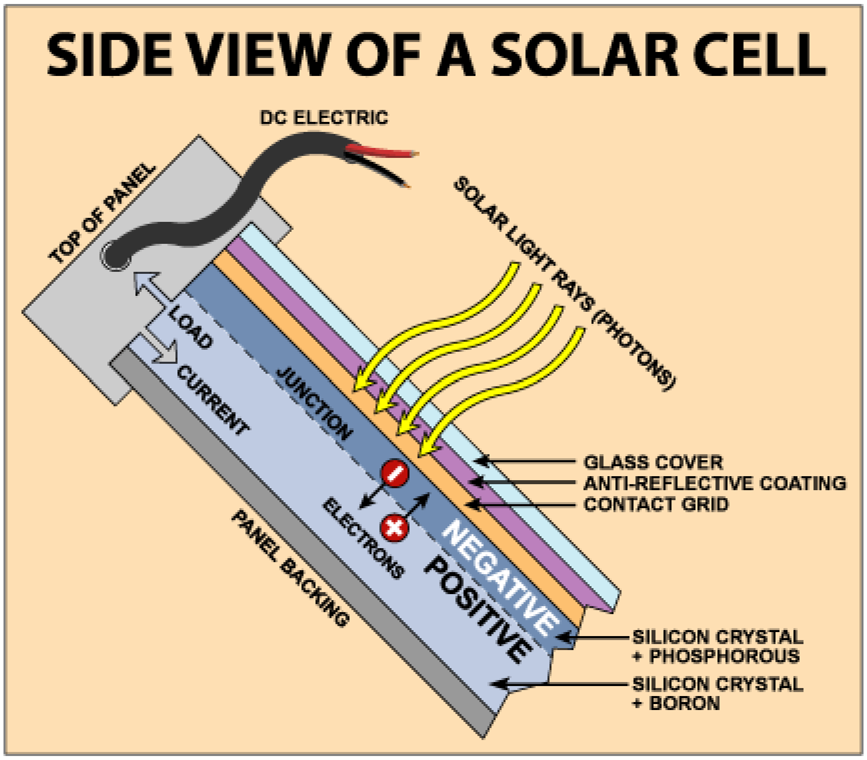


SUN PATH CHART 36 NL
Figure C-3

Appendix D: Photovoltaics / How Solar Cells Work


SOLAR CELL CLOSE-UP

Photovoltaics (or Solar Cells) are solid-state semiconductor devices that convert light into direct-current electricity. These semi-conductors are most commonly made out of silicon crystal, which are used in many electronics and computer components. The top layer of the silicon portion of a solar panel is made from a mixture of this silicon and a small amount of phosphorous, which gives it a negative charge. The inner layer, which constitutes the majority of the panel is a mix of silicon and a little bit of boron, giving it a positive charge. The place where these two layers meet creates an electric field called a junction. When light (or photons) hits the solar cell, before it gets to the silicon crystal to make electricity it passes through a glass cover on the panel and an anti-reflective coating, which stops photons from reflecting off of the panel and being lost. The photons are absorbed into the junction, which pushes electrons in the silicon out of the way (**See illustration below**). If enough photons are absorbed, the electrons are pushed past the junction and flow freely to an external circuit. When converted to Alternating Current electricity using what is called an inverter, this energy can be used to power anything that uses electricity.



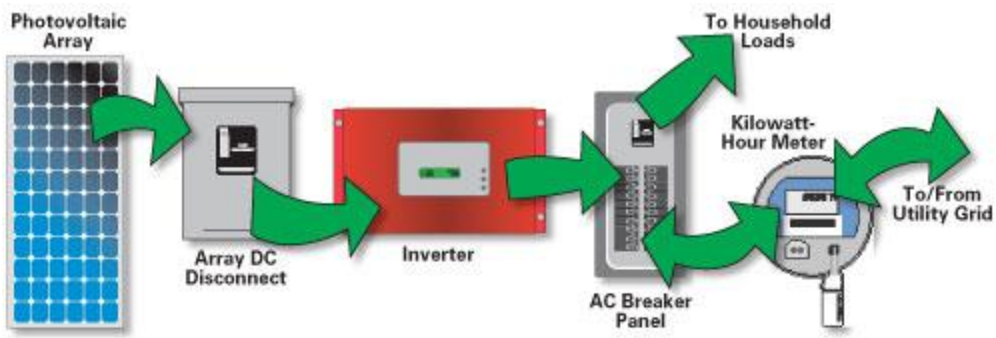
Appendix E: Solar Electricity System Diagrams – 3 Types

The three most common types of solar-electric systems are grid-inter-tied, grid-inter-tied with battery backup, and off-grid (stand-alone). Each has distinct applications and component needs.

1.) Grid Inter-tied Solar-Electric Systems

Also known as on-grid, grid-tied, or utility interactive (UI), grid-inter-tied solar-electric systems generate solar electricity and route it to the electric utility grid, offsetting a home's or business' electrical consumption and, in some instances, even turning the electric meter backwards. Living with a grid-connected solar-electric system is no different than living with grid power, except that some or all of the electricity you use comes from the sun. In many states, the utility credits a homeowner's account for excess solar electricity produced. This amount can then be applied to other months when the system produces less or in months when electrical consumption is greater. This arrangement is called net metering or net billing. The specific terms of net metering laws and regulations vary from state to state and utility to utility. Consult your local electricity provider or state regulatory agency for their guidelines.

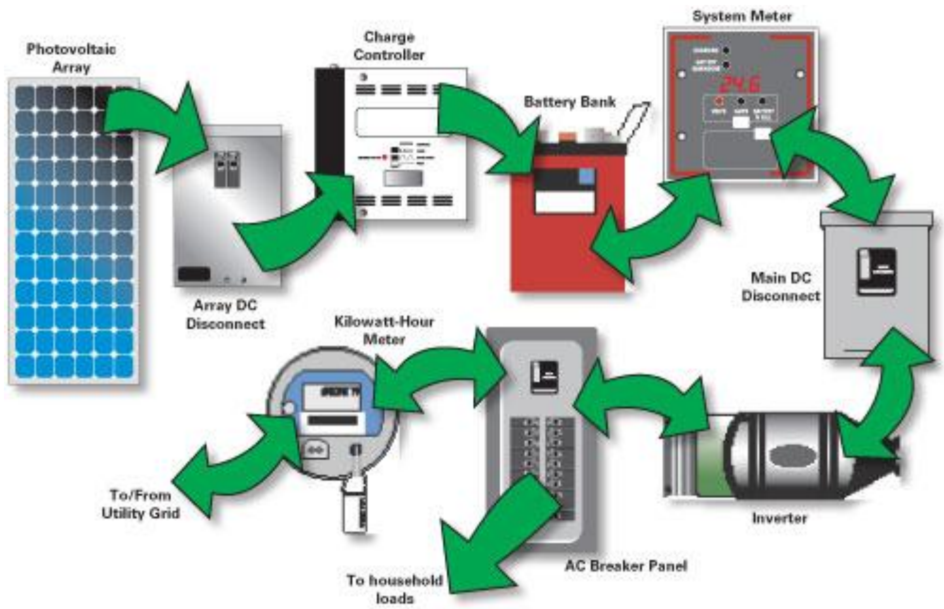
The following illustration includes the primary components of any grid inter-tied solar electric system.



2.) Grid-Inter-tied Solar-Electric Systems with Battery Backup

Without a battery bank or generator backup for your grid inter-tied system, when a blackout occurs, your household will be in the dark, too. To keep some or all of your electric needs (or "loads") like lights, a refrigerator, a well pump, or computer running even when utility power outages occur, many homeowners choose to install a grid-inter-tied system with battery backup. Incorporating batteries into the system requires more components, is more expensive, and lowers the system's overall efficiency. But for many homeowners who regularly experience utility outages or have critical electrical loads, having a backup energy source is priceless.

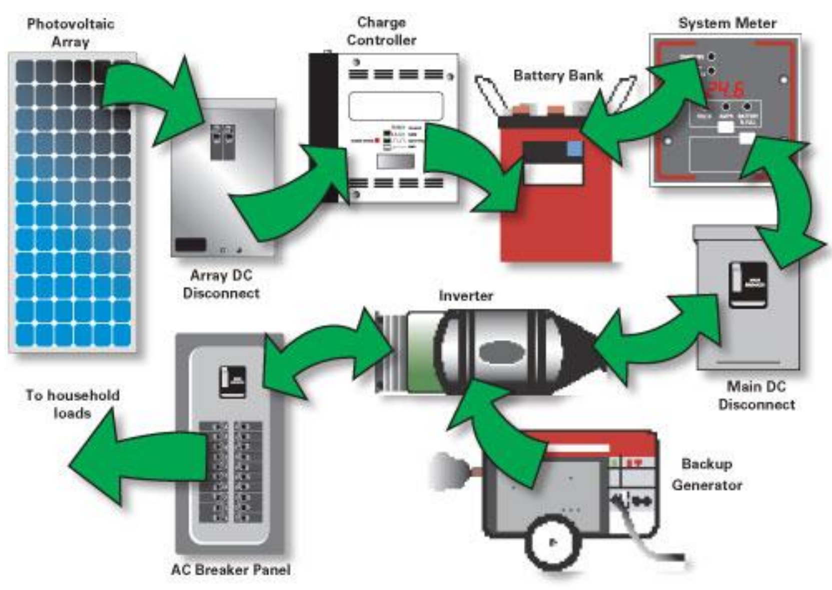
The following illustration includes the primary components of any grid inter-tied solar electric system with battery backup.



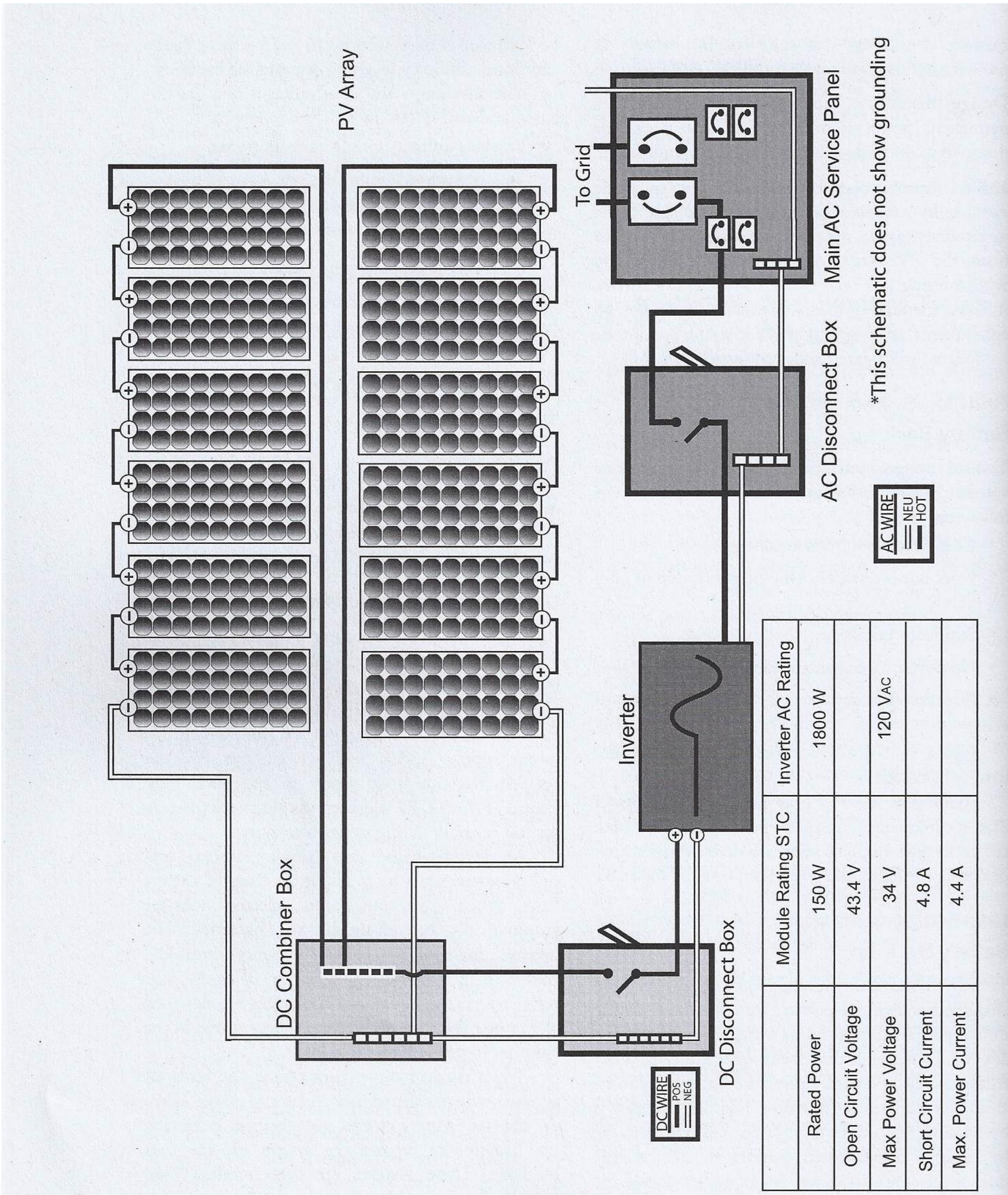
3.) Off-Grid Solar-Electric Systems

Although they are most common in remote locations without utility grid service, off-grid solar-electric systems can work anywhere. These systems operate independently from the grid to provide all of a household's electricity. That means no electric bills and no blackouts—at least none caused by grid failures. People choose to live off-grid for a variety of reasons, including the prohibitive cost of bringing utility lines to remote homesites, the appeal of an independent lifestyle, or the general reliability a solar-electric system provides. Those who choose to live off-grid often need to make adjustments to when and how they use electricity, so they can live within the limitations of the system's design. This doesn't necessarily imply doing without, but rather is a shift to a more conscientious use of electricity.

The following illustration includes the primary components of any off grid solar electric system.



Grid Tied System without Battery Back-up



	Module Rating STC	Inverter AC Rating
Rated Power	150 W	1800 W
Open Circuit Voltage	43.4 V	
Max Power Voltage	34 V	120 VAC
Short Circuit Current	4.8 A	
Max. Power Current	4.4 A	

Figure 11-1

GRID-TIED SYSTEM WITHOUT BATTERY BACK-UP

Grid Tied System with Battery Back-up

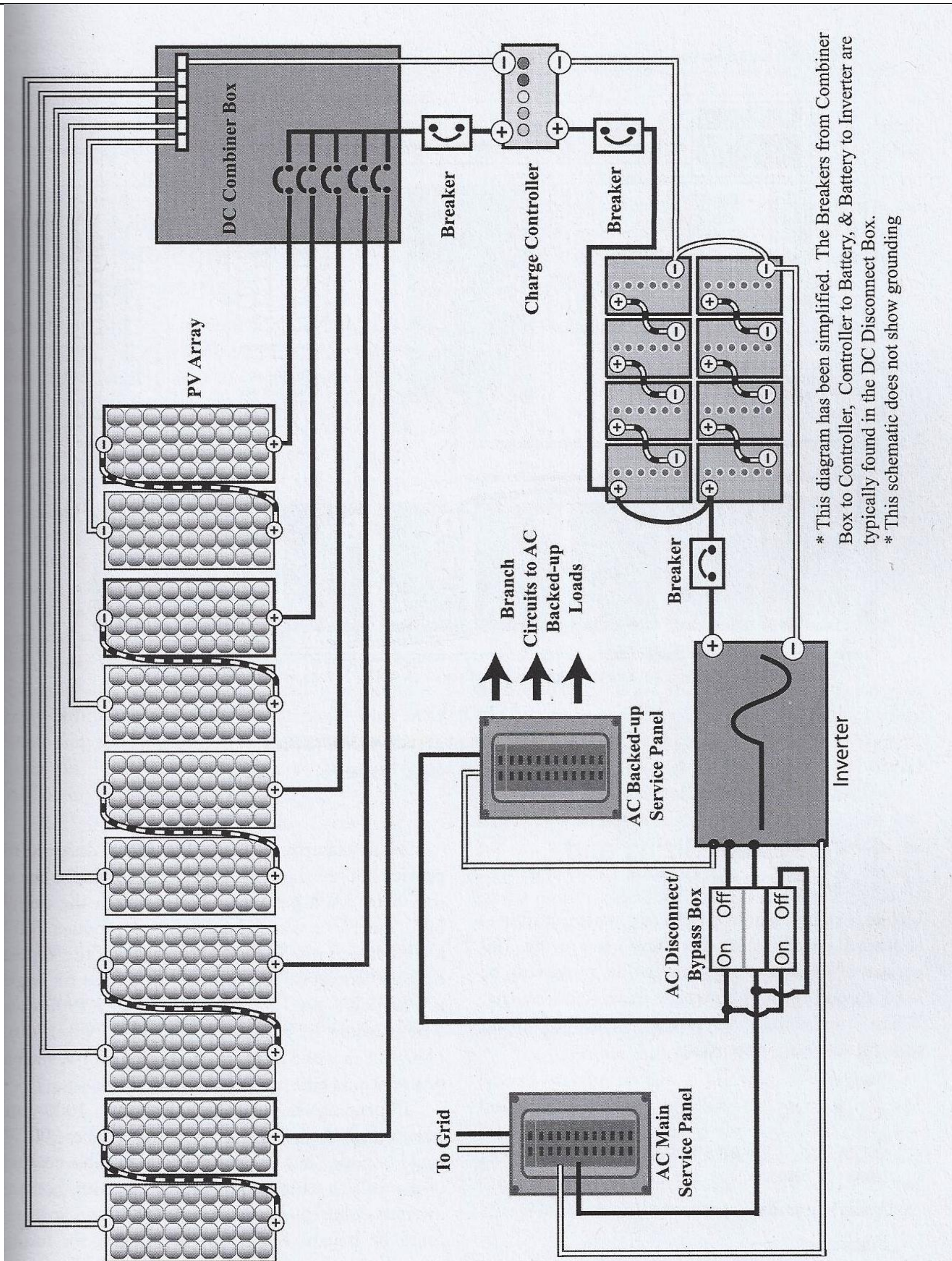


Figure 11-2

GRID-TIED WITH BATTERY BACK-UP SYSTEM

Uninterruptable Power Supply (UPS)

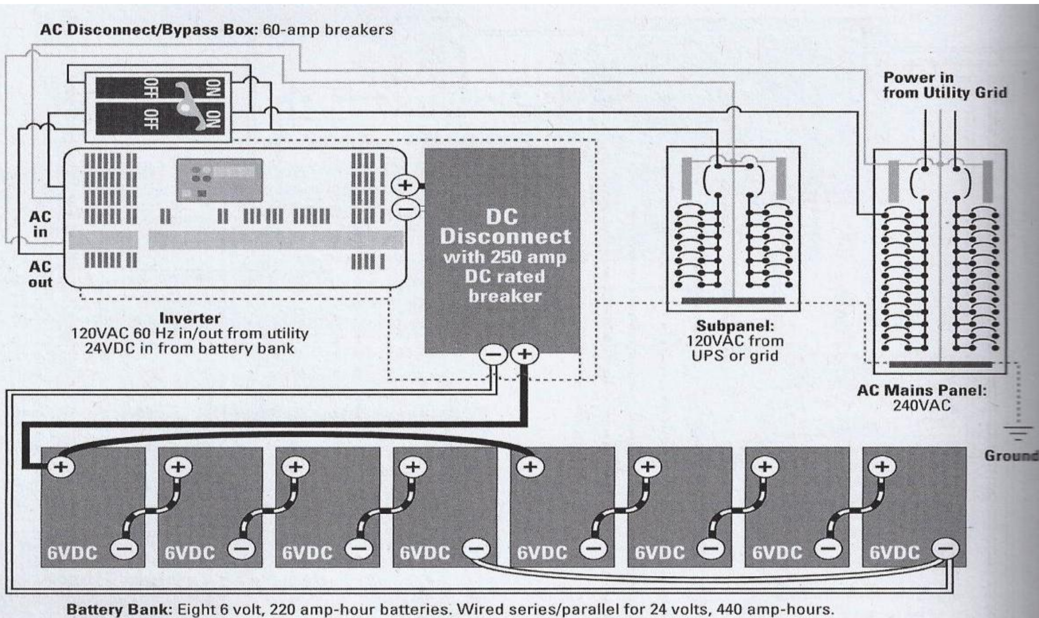


Figure 11-3

UNINTERRUPTIBLE POWER SUPPLY SYSTEM

(Courtesy of *Home Power* Magazine)

Appendix F: **All about** Lightning and Lightning P**rotection**

Lightning is the number one cause of catastrophic failures in solar electric systems and components. The first major reason is that many PV systems are poorly grounded and poorly protected. That is also the 2nd and 3rd major reason.

Step One - Proper Grounding

First off, the NEC Article 780 (NFPA) codes for lightning protection may not be totally adequate for off-grid installations. In fact, in some cases, the recommended practices can actually make it MORE dangerous. Unfortunately, some local inspectors assume that the National Electrical Code book is a bible and will not allow any deviations. For example, Zones of protection, including cones and rolling balls, lack warnings about lightning's' unpredictable nature. These geometric abstractions are presented as factual, rather than statistical levels of protection. This is not to say that you should not follow the NEC recommendations in most cases - but you should be aware that recent research shows that there might be considerable variations from the average. Further steps may be needed for solar systems. NEC grounding is primarily concerned with electrical safety, not lightning protection, and the two may not always be compatible.

The Purpose of Grounding: Equipment: Panel frames and mounts are grounded in order to provide the easiest path for lightning to get to ground. You would much rather have it go down the mounting pole or your ground rod than down your wiring to your controller or inverter. Without proper grounding, lightning can do some really strange things, and can jump around all over while trying to get to earth. If your inverter happens to be in the way, you will probably be buying a new one. You cannot stop lightning, but you can usually direct where you want it to go.

Fuses and Breakers offer NO protection: Fuses and circuit breakers offer no protection at all to lightning strikes. That is not their purpose. Lighting usually lasts for only a few microseconds - much faster than any fuse or breaker can blow. It's pretty unlikely that a one-inch fuse gap is going to offer much protection from a bolt that just cut through two miles of open air. Yet the myth persists that a fuse will offer lighting protection. It will not.

Single Point Grounds!!: The importance of a single-point protection ground cannot be stressed enough. All equipment should be bonded to one single earth ground. If you have some equipment on one ground, and other equipment on another ground, it is quite likely that in a nearby strike that there will be a large voltage difference between the two grounds. This means that the equipment will be at different voltages, sometimes high enough to get arcing from one to another. There is an exception to this: If you have a panel array that is more than 50 feet or so from the rest of the system, it should have it's own frame/mount ground (not electrical ground).

A Single Ground Rod is Seldom Enough: Tests done over the past few years show that in most cases, a single 6 or 8 foot ground rod is NOT enough, even when the ground is salted to improve conductivity. The problem is, in arid climates with dry soil, it could take as many as a dozen rods to get it down to the 10 ohms ground resistance that is usually accepted as the optimum (25 ohms is the NEC minimum). To get down to the 25 ohm NEC minimum, you may have to use 2-3 10 foot rods, all bonded together with #6 wire and copper wire clamps. However, if you cannot do this, something is better than nothing. In some cases you may have to go so far as to bury lengths of bare copper wire or copper pipe in trenches.

Grounding and NEC Requirements

The NEC requires that all exposed metal surfaces be grounded regardless of the nominal system voltage. Systems with PV open-circuit voltages below 50 Volts are not required to have one of the current-carrying conductors grounded. Any system with ac voltages at 120 volts must have the neutral grounded. Some inverters do not isolate the ac and DC sides; grounding the ac neutral will also ground the DC negative. Other inverters have the case (which must be grounded) connected to the negative input which grounds the negative current-carrying conductor.

The NEC requirement can be extended. A separate conductor (as large as possible, but not less than number 10 AWG) should be fastened to each metallic module frame with a self-threading, stainless-steel screw. The other end of these conductors should be connected to a single point on the array frame or rack â€¹ again with another self-threading, stainless-steel screw or with a stainless-steel bolt in a drilled and tapped hole. From this point, number 4-6 AWG or larger copper conductor should be run directly to the nearest earth where it is connected to the longest, deepest ground rod that can be afforded. Eight feet is the minimum length recommended. Use a UL-listed clamp to make the connection. If a steel well casing is available, drill and tap the casing and use this as the ground rod.

In dry areas, several ground rods spaced 20-50 feet apart in a radial configuration, all bonded to the central rod can be effective. Buried copper water pipe can also improve the grounding system. Pipe or copper wire can be buried in trenches 12-18 inches deep in a radial grid. All grounding members should be connected or bonded to the central ground rod with heavy, bare conductors buried under ground. Direct-burial, UL-listed grounding clamps or welding should be used for all connections. Soldering should never be used for underground connections - it can corrode underground due to the different metals.
You can't get a "perfect" ground unless you are prepared to spend megabucks on buried copper cables. However, a good ground is possible to get in most areas and need not be expensive. In dry and/or rocky locations, it may be more of a "challenge". If you can't get it perfect, ANYTHING is better than nothing at all. If you have bedrock at 3 feet, try driving in 3 to 6 short ground rods and tie them all together with at least #4 wire and good clamps. - not perfect, but far better than nothing. Another way is to bury heavy wire or (usually cheaper) lengths of copper pipe in ditches. Keeping the ground wet and/or salting the nearby area will also help.

The negative side of the battery bank should be grounded to the same point as all other ground wires. Batteries usually have a very low internal resistance, and can help act like a large surge arrestor on all but a direct hit. This may stop a hit near your panels from jumping around to your inverter and other equipment. The ground wire should be at least #8, and #6 or #4 is recommended.

Surge Arrestors

Surge arrestors act like "clamps" in most cases. They go across the live wires with another wire going to ground. Normally they just sit there, but if the voltage goes above a certain level, they start to conduct, shorting the higher voltage to ground. In lighting prone areas you should also install a surge capacitor - this is not really an arrestor, but acts extremely fast, and will catch those high voltage spikes on the AC line that are too fast for a surge arrestor. For most systems to get the best protection, you should have a DC surge arrestor, such as the LA302DC on the side coming from the array - this should go on the INPUT to the charge controller. It should be as near the charge controller as possible. On the AC side (and this applies to BOTH the inverter AC input and AC output (for generator and/or grid tie systems) you should have both an AC surge arrestor and a surge capacitor.

Most inverter damage is caused by surges on the AC side coming in through house or generator wiring. In many systems with a backup generator, the generator is located outside, quite some distance from the inverter, and is a common hit point for lightning strikes. The Delta LA302R AC surge arrestor and the CA302 surge capacitor should be used on the AC portions. The benefits of also putting arrestors at the generator end are not all that great, and if installed you will probably need a separate ground rod system.

The Delta arrestors are not perfect, but they work a lot better than nothing. Better arrestors are available, but the problem is price - complete system protection using the Polyphaser units could easily cost over $1000. The biggest problem with the Delta arrestors is that they may not always trigger on "low "level" spikes, but if you also have a surge capacitor installed, that will catch most of those.

It may seem a bit high to spend over $200 on surge arrestors, but the typical repair bill for large sine wave inverter that has been lightning hit can run well over $1000. Delta Surge arrestors and capacitors may be ordered from our online store.

Installing Delta Arrestors

Most of the Delta surge arrestors that we sell have 3 wires (a few, for pumps, have 4). In all cases, the GREEN wire is ground, the black and white wires are wired across the AC or the DC power side. Even though the white in most AC systems is neutral, and is supposedly grounded, don't count on it - make sure you have both sides protected. In DC systems, such as PV arrays, it really does not matter much which of the two wires go to what, but again both sides of the input to the charge controller or whatever the panels are feeding should have one wire from the arrestor attached. To protect a 3-phase submersible pump motor, connect the black wires to the line terminals and the white and/or green wire to the casing ground. Most of the arrestors that we sell have a separate green ground wire - this wire should ALWAYS be attached to a good ground.

Electrical Grounding Diagrams

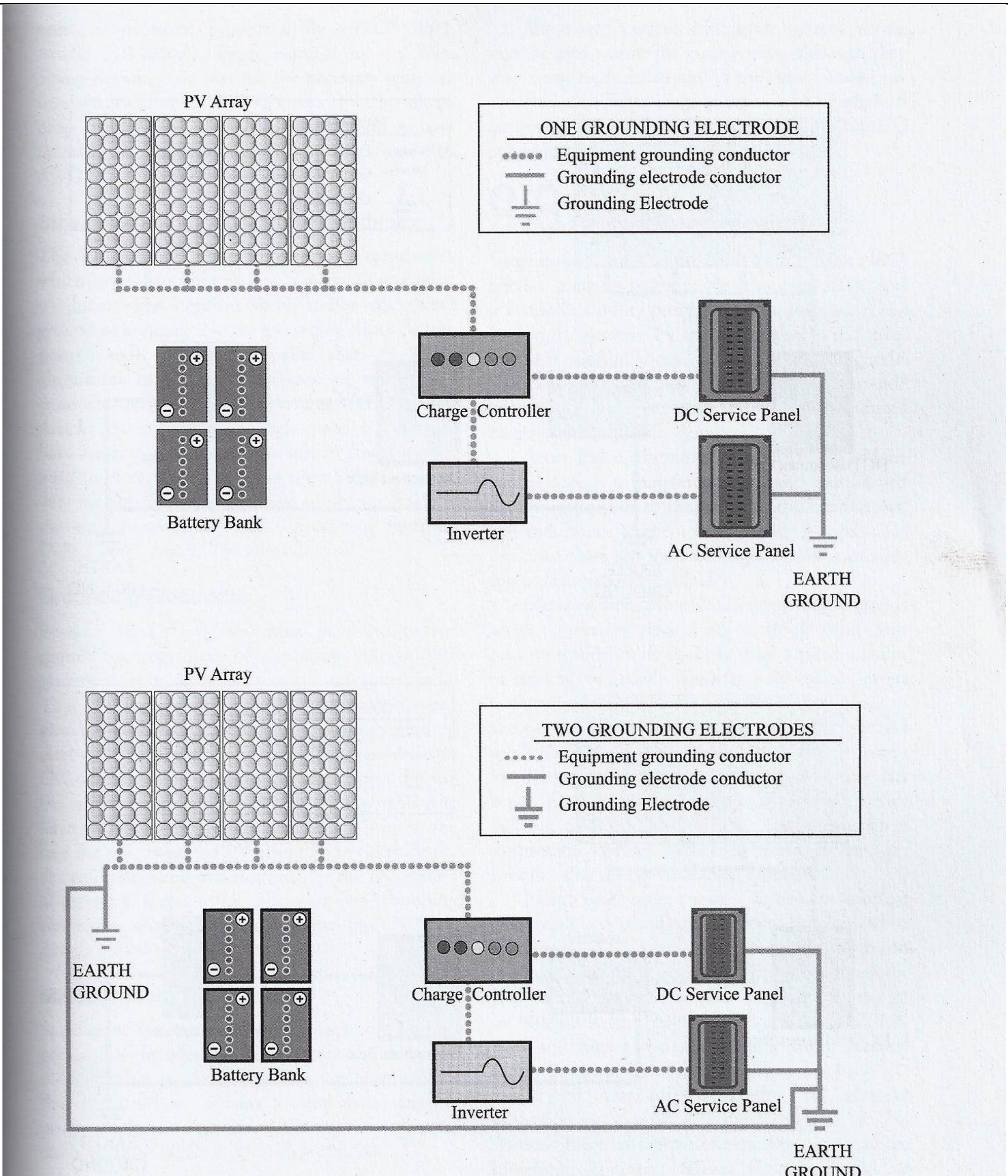


Figure 9-3

EQUIPMENT GROUNDING SCHEMATIC FOR A STAND-ALONE SYSTEM

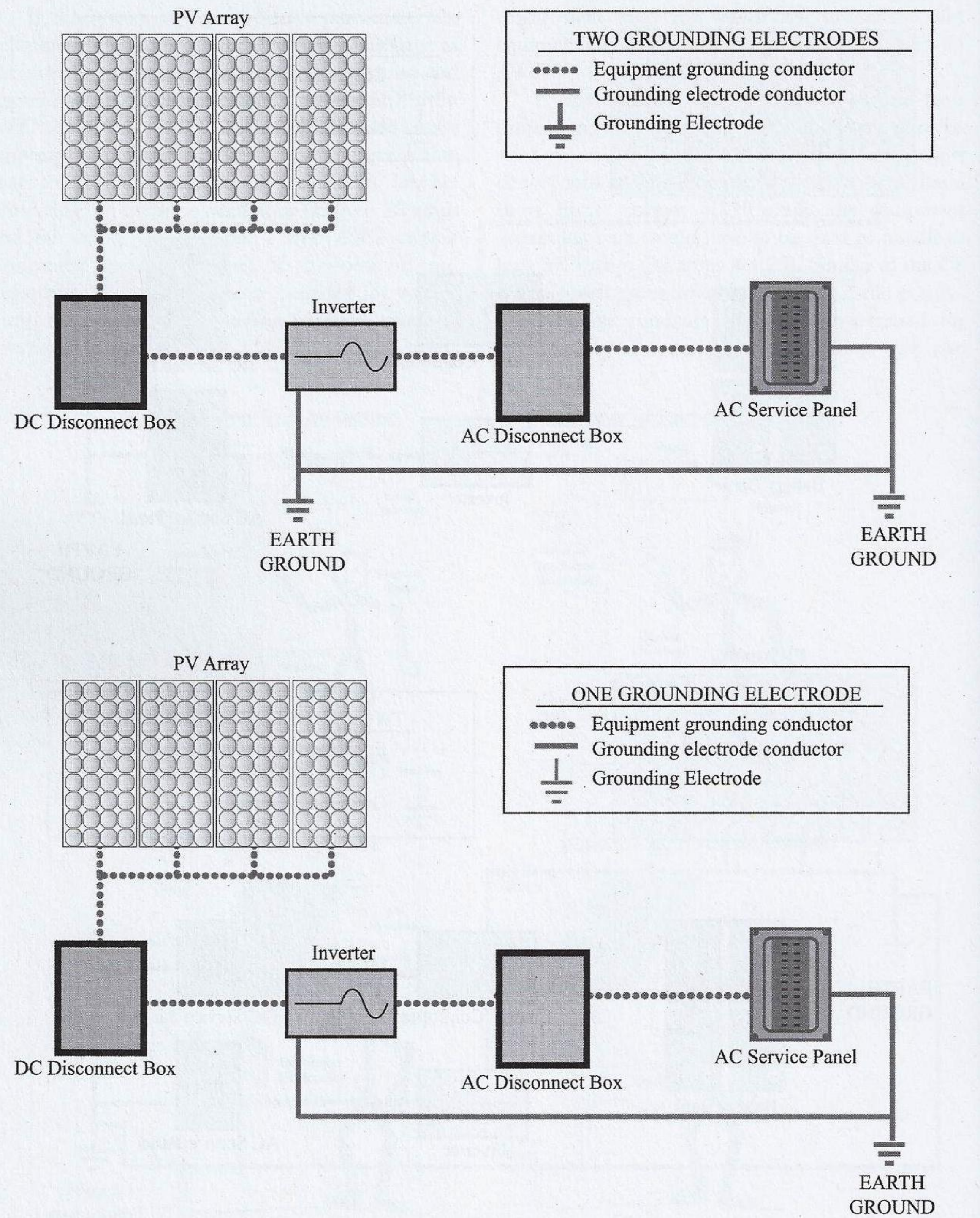


Figure 9-4

EQUIPMENT GROUNDING SCHEMATIC FOR A GRID-TIED SYSTEM

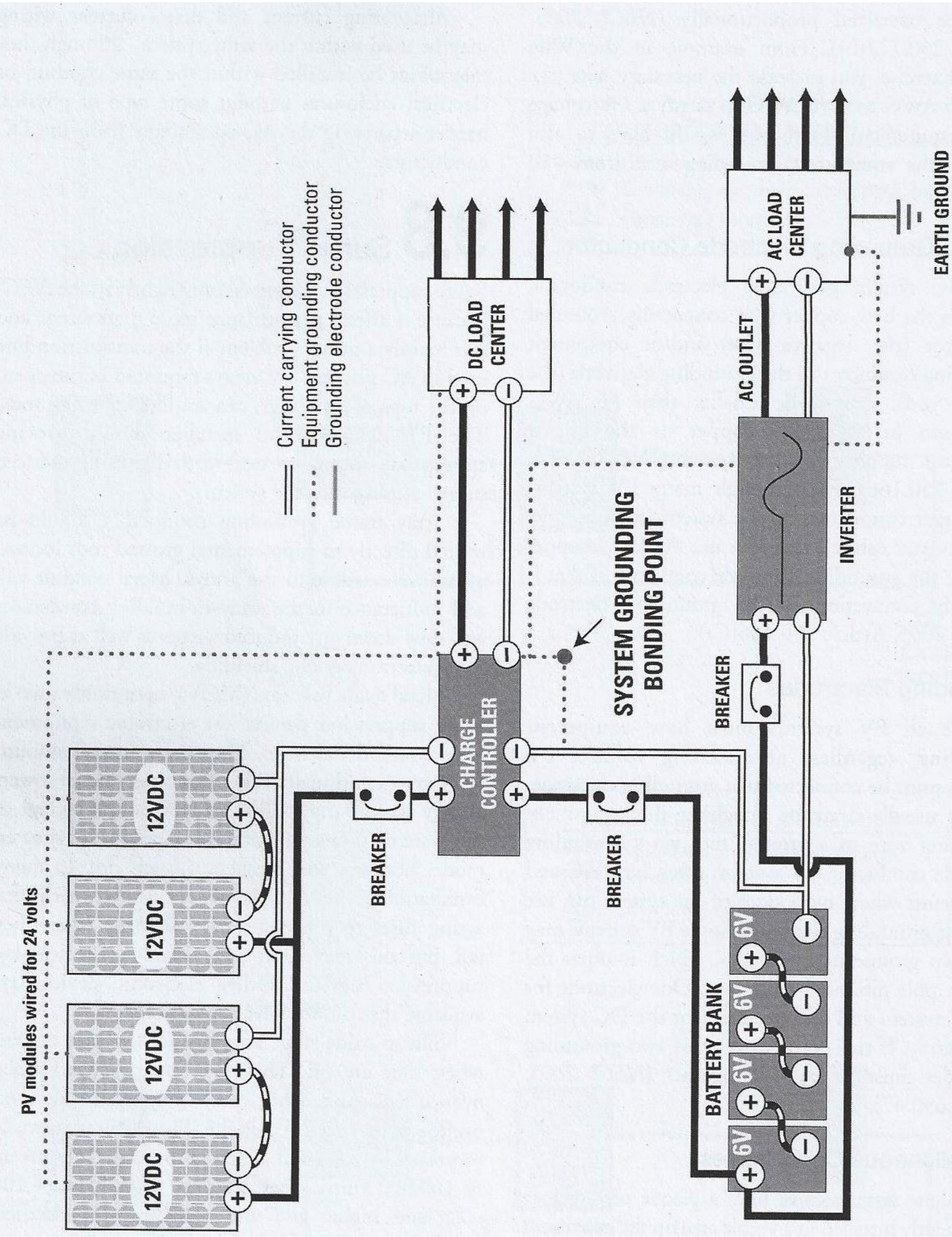


Figure 9-5

SYSTEM AND EQUIPMENT GROUNDING SCHEMATIC

Appendix G: Return on Investment (ROI) Determination

1 KW (solar array) * 5 hrs sunlight / day = 5 KW-hrs/day * 30 days / month =
150 KW-hrs / month per KW of solar panels in the mid-Atlantic region.

Average Electric Bill / month	electric rate in $/KW-hr.	KW-hrs. used per month	Total # of KW needed to go off-grid	savings per year per each KW-hr. of solar array	30% Fed. Tax Credit & #yrs to pay-off at DIY $4k/KW	30% Fed. Tax Credit & #yrs to pay-off at Installer $6k/KW
$100	$0.08	1250	8.3	$144	19.4	29.2
$100	$0.10	1000	6.7	$180	15.6	23.3
$100	$0.12	833	5.6	$216	13.0	19.4
$100	$0.14	714	4.8	$252	11.1	16.7
$100	$0.16	625	4.2	$288	9.7	14.6
$100	$0.18	556	3.7	$324	8.6	13.0
$150	$0.08	1875	12.5	$144	19.4	29.2
$150	$0.10	1500	10.0	$180	15.6	23.3
$150	$0.12	1250	8.3	$216	13.0	19.4
$150	$0.14	1071	7.1	$252	11.1	16.7
$150	$0.16	938	6.3	$288	9.7	14.6
$150	$0.18	833	5.6	$324	8.6	13.0
$200	$0.08	2500	16.7	$144	19.4	29.2
$200	$0.10	2000	13.3	$180	15.6	23.3
$200	$0.12	1667	11.1	$216	13.0	19.4
$200	$0.14	1429	9.5	$252	11.1	16.7
$200	$0.16	1250	8.3	$288	9.7	14.6
$200	$0.18	1111	7.4	$324	8.6	13.0
$250	$0.08	3125	20.8	$144	19.4	29.2
$250	$0.10	2500	16.7	$180	15.6	23.3
$250	$0.12	2083	13.9	$216	13.0	19.4
$250	$0.14	1786	11.9	$252	11.1	16.7
$250	$0.16	1563	10.4	$288	9.7	14.6
$250	$0.18	1389	9.3	$324	8.6	13.0
$300	$0.08	3750	25.0	$144	19.4	29.2
$300	$0.10	3000	20.0	$180	15.6	23.3
$300	$0.12	2500	16.7	$216	13.0	19.4
$300	$0.14	2143	14.3	$252	11.1	16.7
$300	$0.16	1875	12.5	$288	9.7	14.6
$300	$0.18	1667	11.1	$324	8.6	13.0
$350	$0.08	4375	29.2	$144	19.4	29.2
$350	$0.10	3500	23.3	$180	15.6	23.3
$350	$0.12	2917	19.4	$216	13.0	19.4
$350	$0.14	2500	16.7	$252	11.1	16.7
$350	$0.16	2188	14.6	$288	9.7	14.6
$350	$0.18	1944	13.0	$324	8.6	13.0
$400	$0.08	5000	33.3	$144	19.4	29.2
$400	$0.10	4000	26.7	$180	15.6	23.3
$400	$0.12	3333	22.2	$216	13.0	19.4
$400	$0.14	2857	19.0	$252	11.1	16.7
$400	$0.16	2500	16.7	$288	9.7	14.6
$400	$0.18	2222	14.8	$324	8.6	13.0

Taking the example above with a $150 per month electric bill and an electric rate of $0.10 per KW-hr. -- my Potomac Edison (First Energy) electric needs will be offset by a **5 KW** solar power system.

Type	cost/KW	system size	Total Cost	30% Federal rebate	WV $2,000 rebate year 1	WV $2,000 rebate year 2
DIY Install:	$4,000 *	5 KW	$20,000	$6,000	$2,000	$2,000
Installer based:	$6,000 *	5 KW	$30,000	$6,000	$2,000	$2,000

Type	Net cost after rebates and incentives	5 KW - total annual savings of $180/KW solar per year	Pay-off time - in years:
DIY Install:	$10,000.00	$900	11.1
Installer based:	$20,000.00	$900	22.2

In this case, the state incentives have a larger impact on a smaller number - i.e. DIY install, as the reimbursements from the state of WV have a ceiling of $2,000 which we took over 2 years - phase I and phase II of the install over 2 separate years -- i.e. December and January crosses over years.

So assuming that my install is DIY and I pay off my 5 KW solar power system in 11 years, and my panels continue to supply power for 30 years and my electric rate never goes up (not true!) --- my gross savings over 30 years for this system would be: (30 -11 years) *$180*5 = $17,100.

But wait, I can sell SREC's (Solar Renewable Energy Credits) to a buyer and net another $200 per KW per year for perhaps 10 years -- nets another $1,000 per year or $10,000 over 10 years -- so my system ends up being FREE and the pay-off is even more rapidly accelerated with the SREC contract...

November SREC Prices	Energy Year Ending		
State	2010	2011	2012*
Delaware	-	-	$88.99
Maryland In-State	$174.98	$200.00	
Maryland Out-of-State	-	-	
Massachusetts	-	$535.00**	
New Jersey	-	$670.00	$225.00
Ohio In-State	-	$380.00	
Ohio Out-of-State	-	$55.00	
Pennsylvania	-	$10.00	-
Washington, DC	$119.00	$150.00	

source: http://www.srectrade.com/blog/tag/solar-rec-prices

Federal and State Renewable Energy Incentives, Tax Credits and Rebates

OffGridWinchester

A Resource for Independent and Off-Grid Living, Education, & Training

DIY Workshops on Solar Power, Solar Thermal, and Wind Power
at locations in downtown Winchester and downtown Berryville VA

www.OffGridWinchester.com

Federal and State Renewable Energy Incentives, Tax Credits & Rebates:

From: www.dsireusa.org – database of state incentives for renewable energy.

State	Type of Incentive	Percentage / Max $ Amount	Additional Details
Federal	Residential Renewable Energy Tax Credit	30%	Solar-electric systems placed in service before 1/1/2009: $2,000 Solar-electric systems placed in service after 12/31/2008: no maximum Solar water heaters placed in service before 1/1/2009: $2,000 Solar water heaters placed in service after 12/31/2008: no maximum Wind turbines placed in service in 2008: $4,000 Wind turbines placed in service after 12/31/2008: no maximum
Federal			
State	**Type of Incentive**	**Percentage / Max $ Amount**	**Additional Details**
Virginia	Property Tax Exemption for Solar	varies	Passive Solar Space Heat, Solar Water Heat, Solar Space Heat, Solar Thermal Electric, Photovoltaics
Virginia			

State	Type of Incentive	Percentage / Max $ Amount	Additional Details
West Virginia	Residential Solar Energy Tax Credit	30% $2,000 max.	Eligible: Solar Water Heat, Solar Space Heat, Photovoltaics
West Virginia			
State	**Type of Incentive**	**Percentage / Max $ Amount**	**Additional Details**
Maryland	Sales and Use Tax Exemption for Renewable Energy Equipment	100% exemption	Solar Water Heat, Solar Space Heat, Solar Thermal Electric, Photovoltaics, Wind, Geothermal Heat Pumps
Maryland	Sales and Use Tax Exemption for Residential Solar and Wind Electricity Sales	100% exemption from sales and use tax	Photovoltaics, Wind

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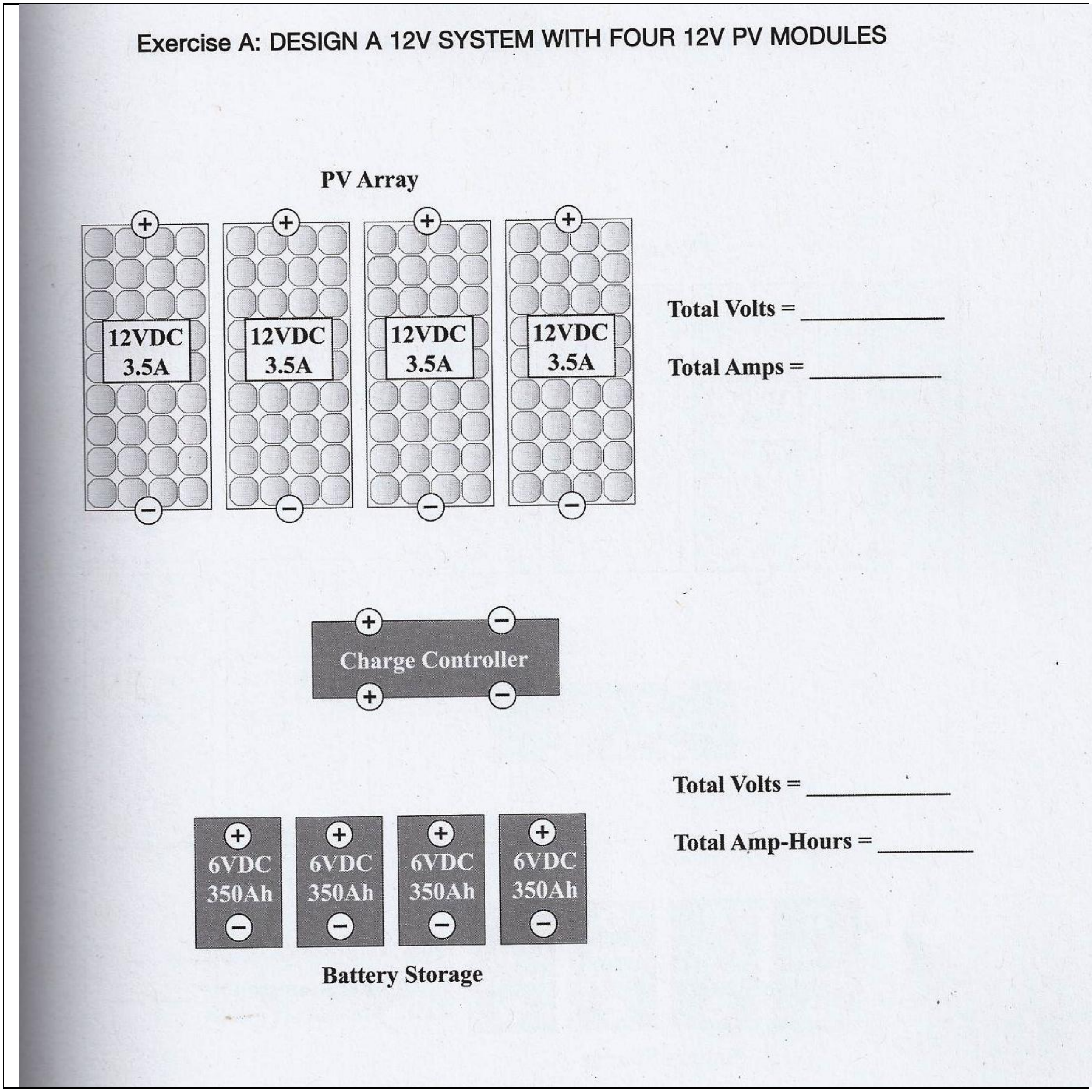
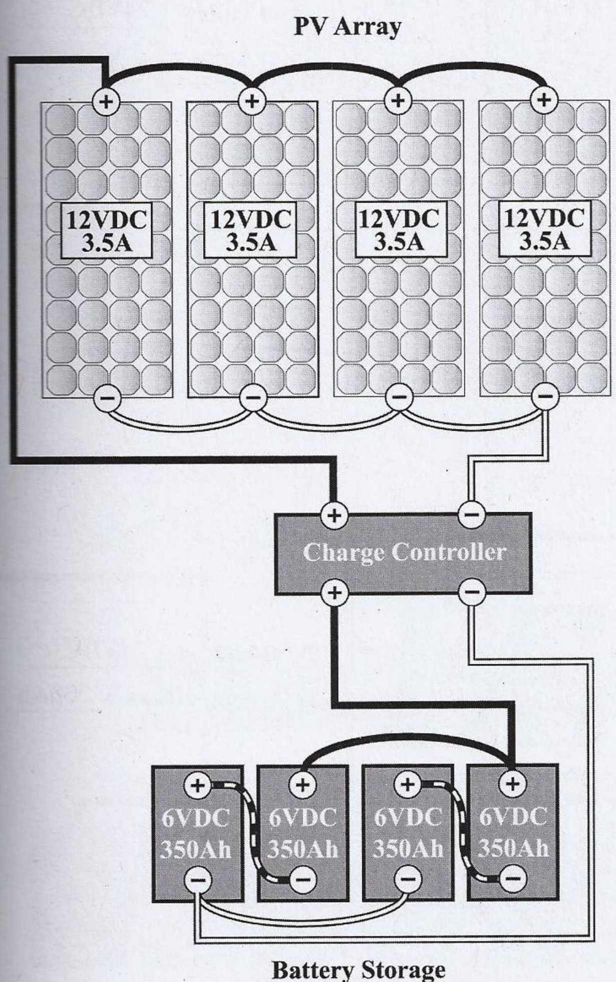
www.OffGridWinchester.com

Appendix H

6 exercises to understand system design, 12, 24, and 48 volts systems and parallel and series wiring for panels and batteries



Answer A: 12V SYSTEM WITH FOUR 12V PV MODULES



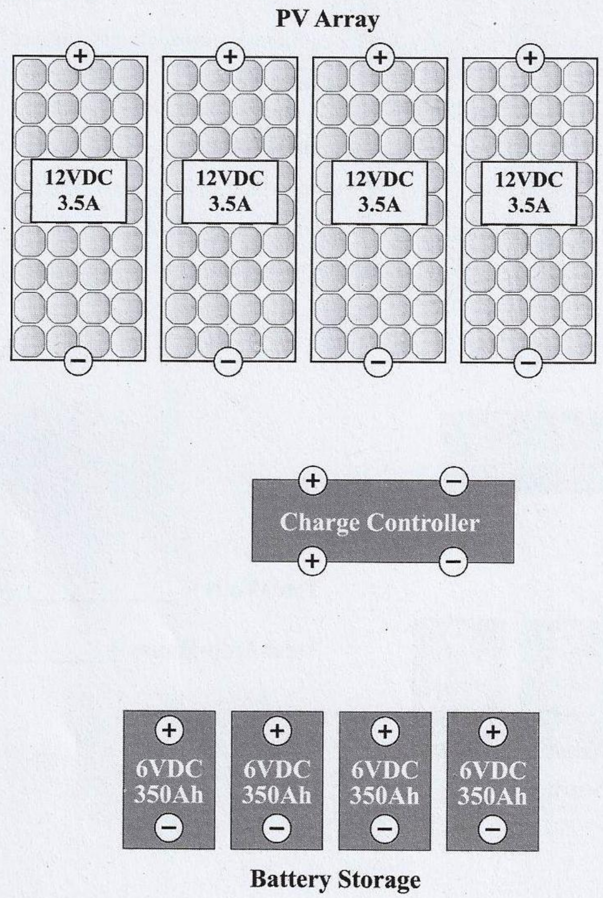
Total Volts = 12VDC

Total Amps = 14A

Total Volts = 12VDC

Total Amp-Hours = 700Ah

Exercise B: DESIGN A 24V SYSTEM WITH FOUR 12V PV MODULES



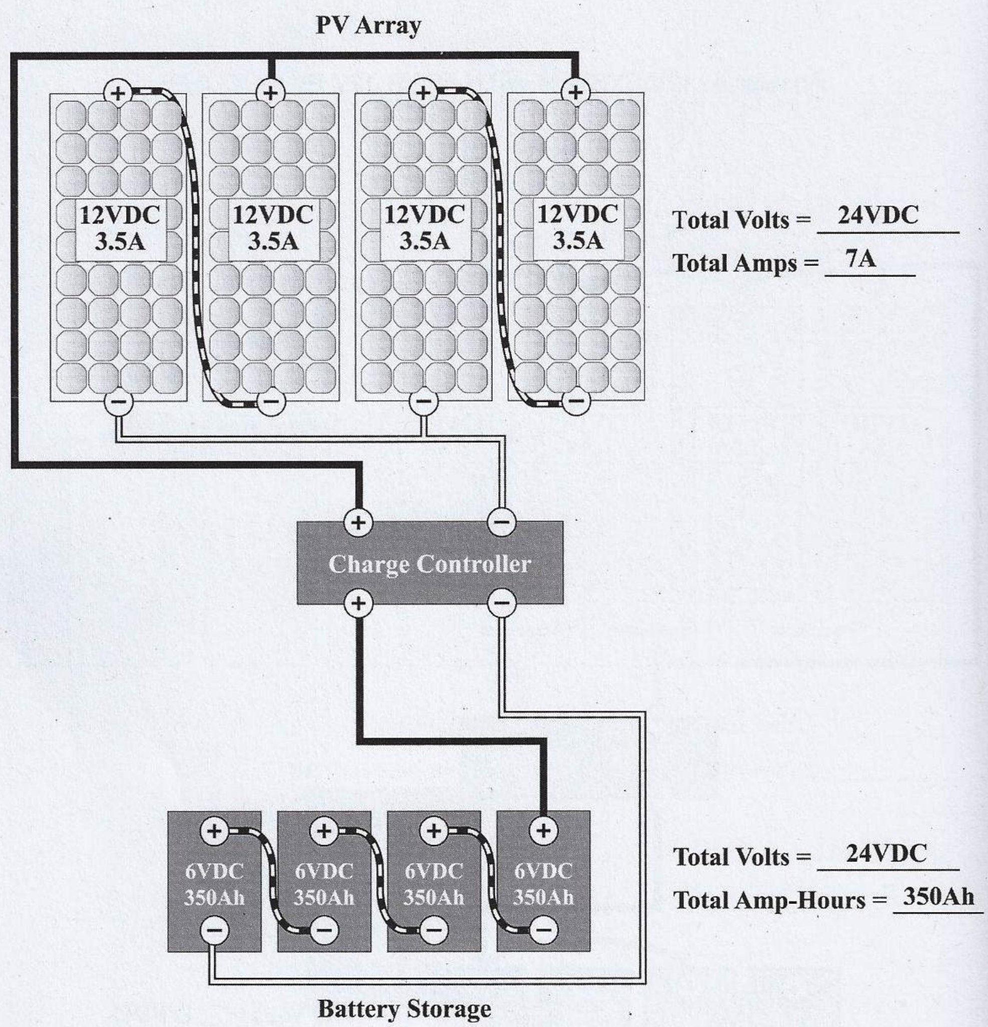
Total Volts = ___________

Total Amps = _______

Total Volts = ___________

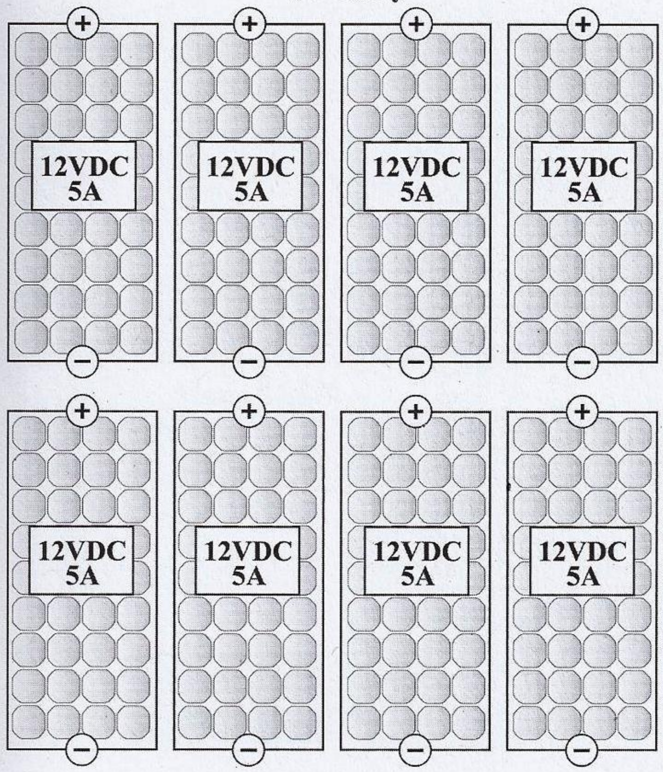
Total Amp-Hours = _______

Answer B: 24V SYSTEM WITH FOUR 12V PV MODULES



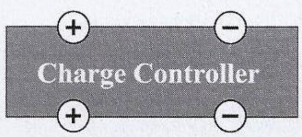
Exercise C: DESIGN A 48V SYSTEM WITH EIGHT 12V PV MODULES

PV Array



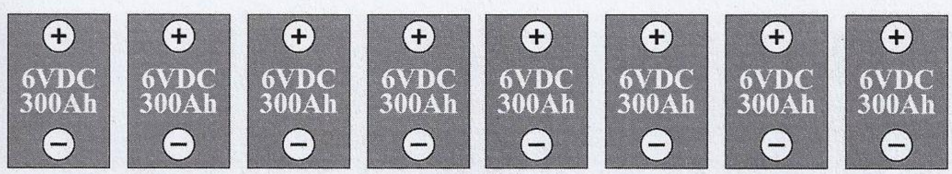
Total Volts = __________

Total Amps = __________



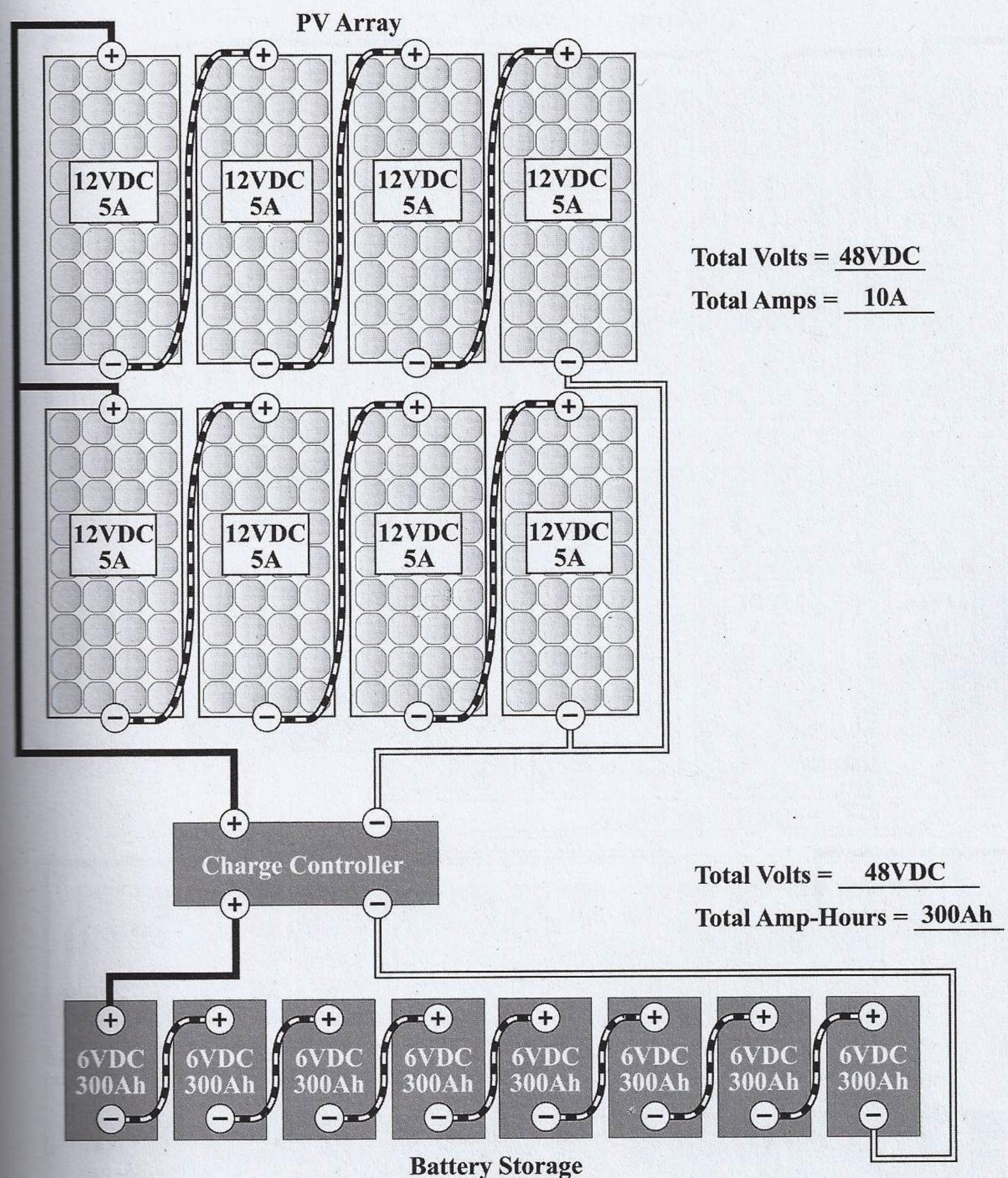
Total Volts = ____________

Total Amp-Hours = ________



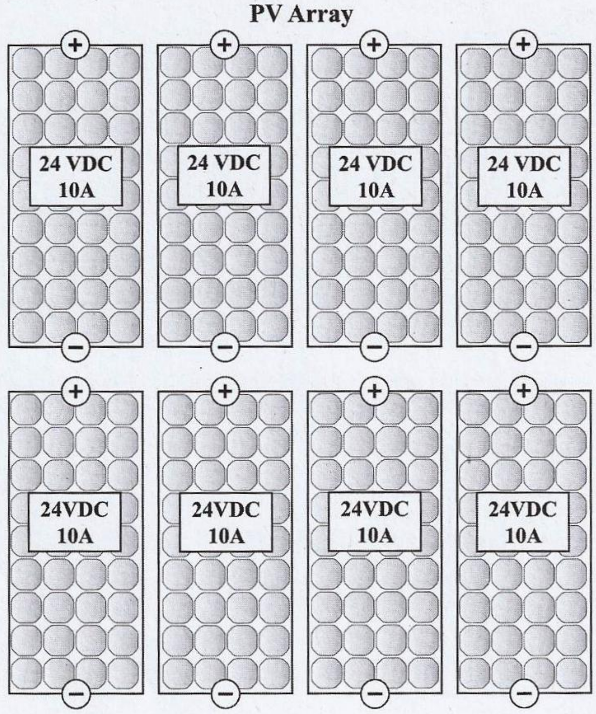
Battery Storage

Answer C: 48V SYSTEM WITH EIGHT 12V PV MODULES



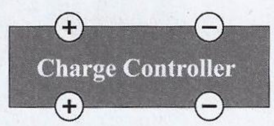
Exercise D: DESIGN A 48V SYSTEM WITH EIGHT 24V PV MODULES

PV Array



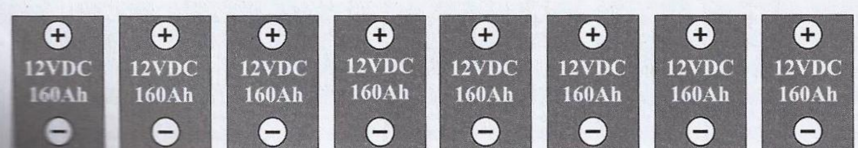
Total Volts = ___________

Total Amps = ___________



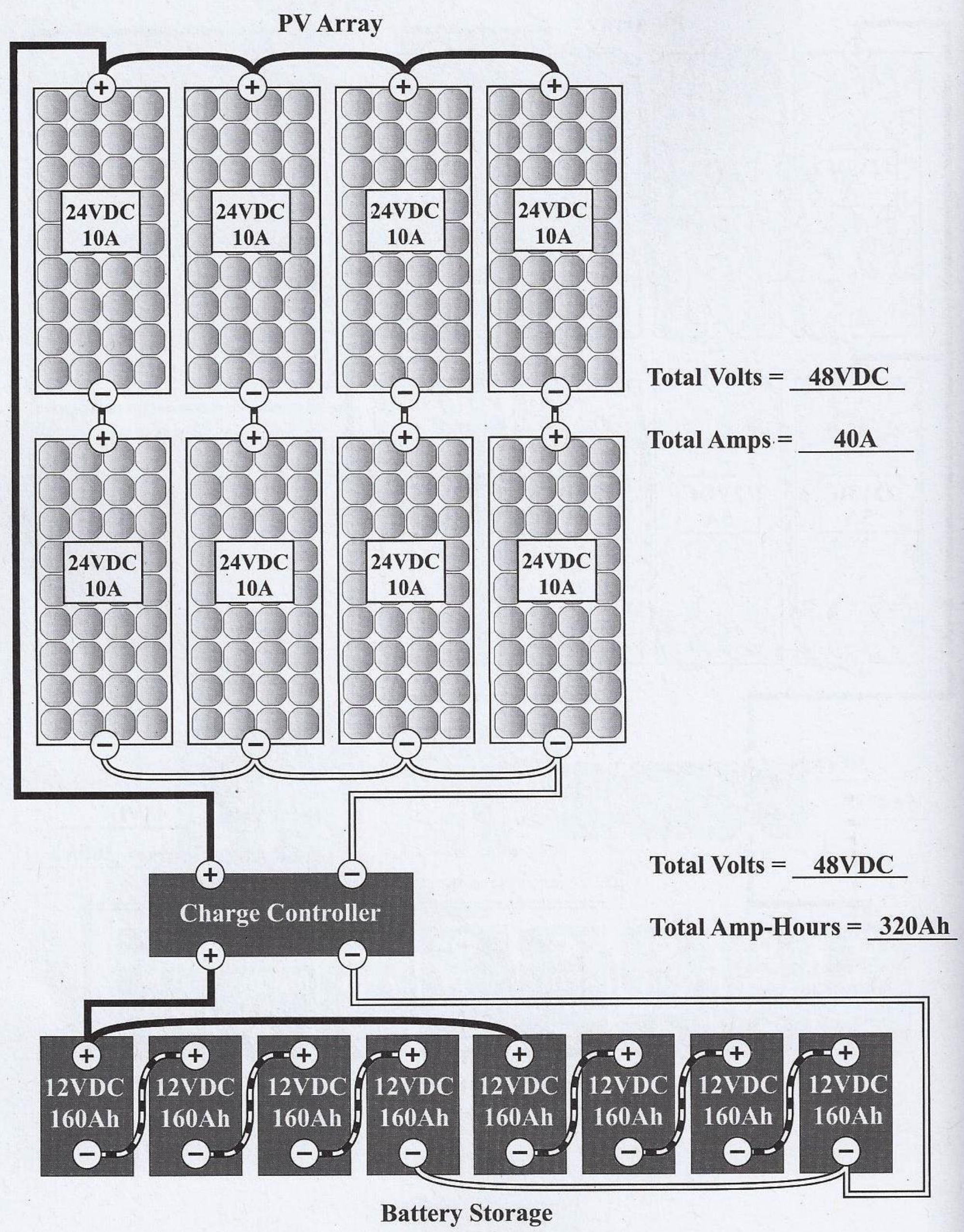
Total Volts = ___________

Total Amp-Hours = ________



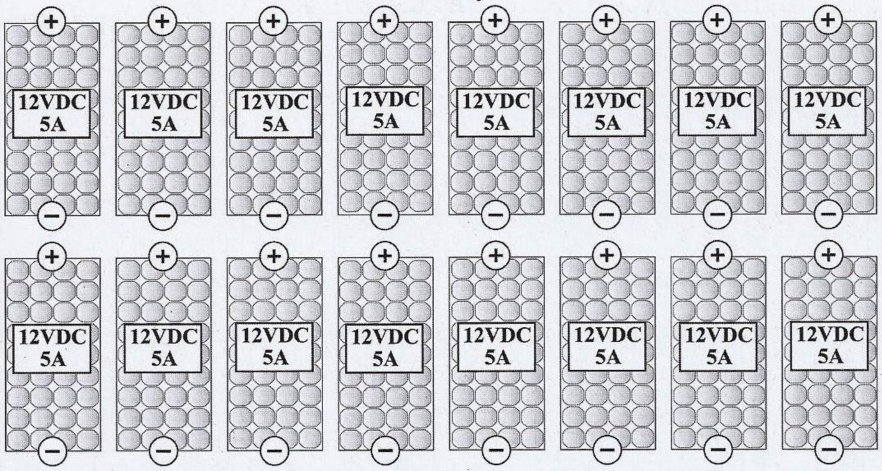
Battery Storage

Answer D: 48V SYSTEM WITH EIGHT 24V PV MODULES



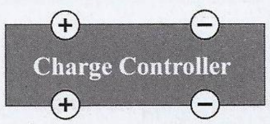
Exercise E: DESIGN A 48V SYSTEM WITH SIXTEEN 12V PV MODULES

PV Array



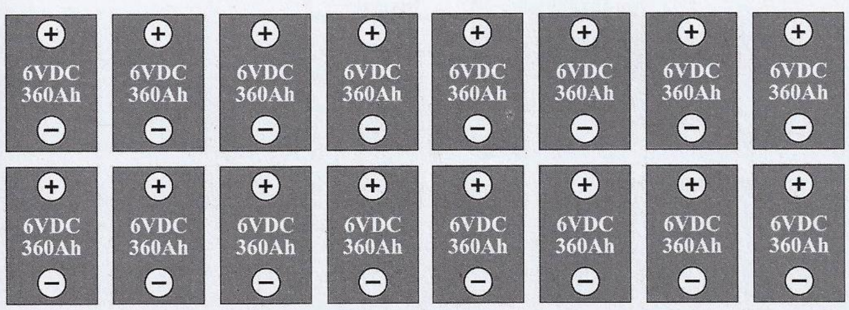
Total Volts = ___________

Total Amps = _______



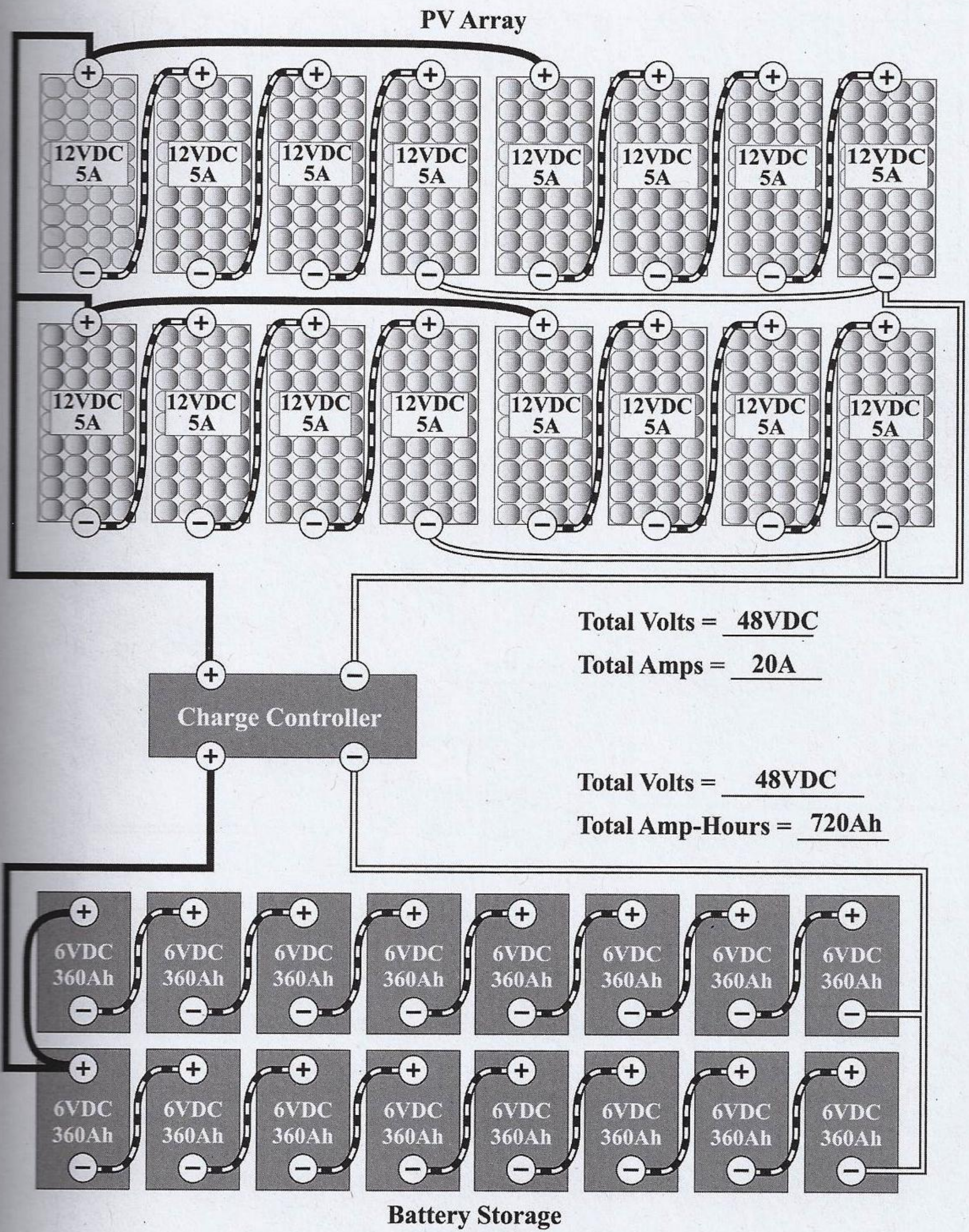
Total Volts = ___________

Total Amp-Hours = _______

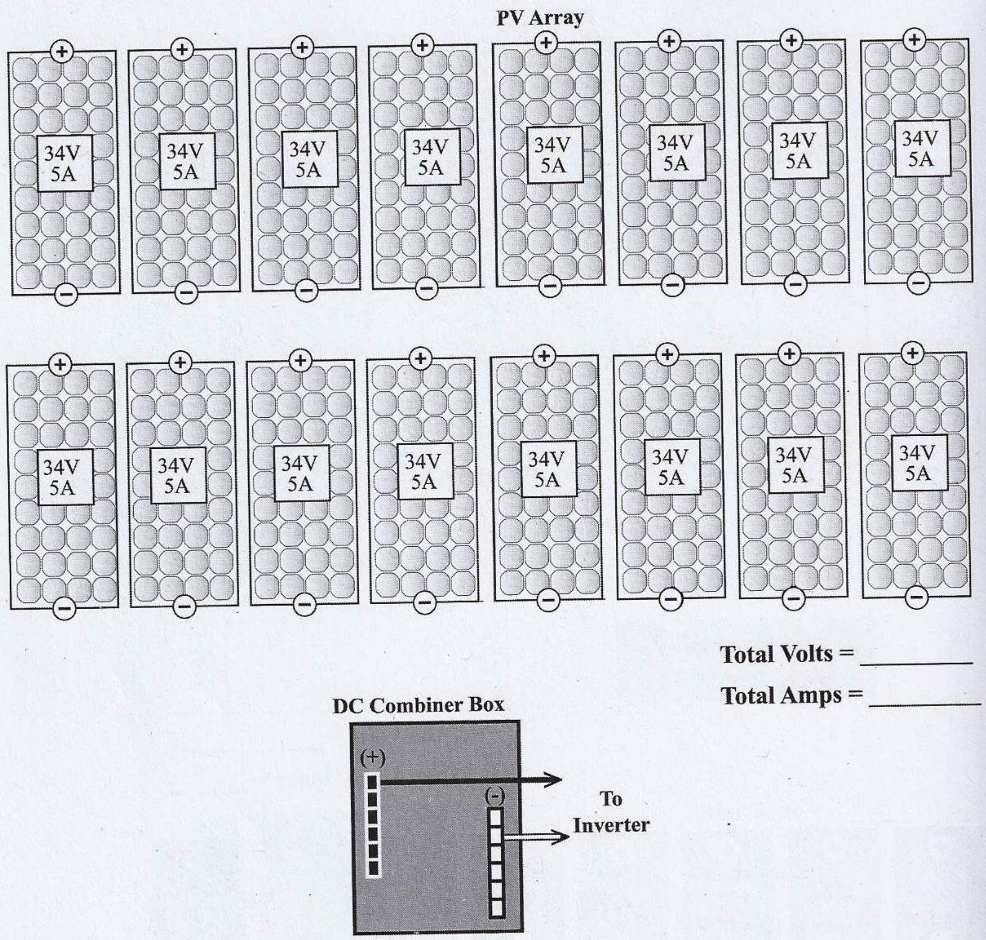


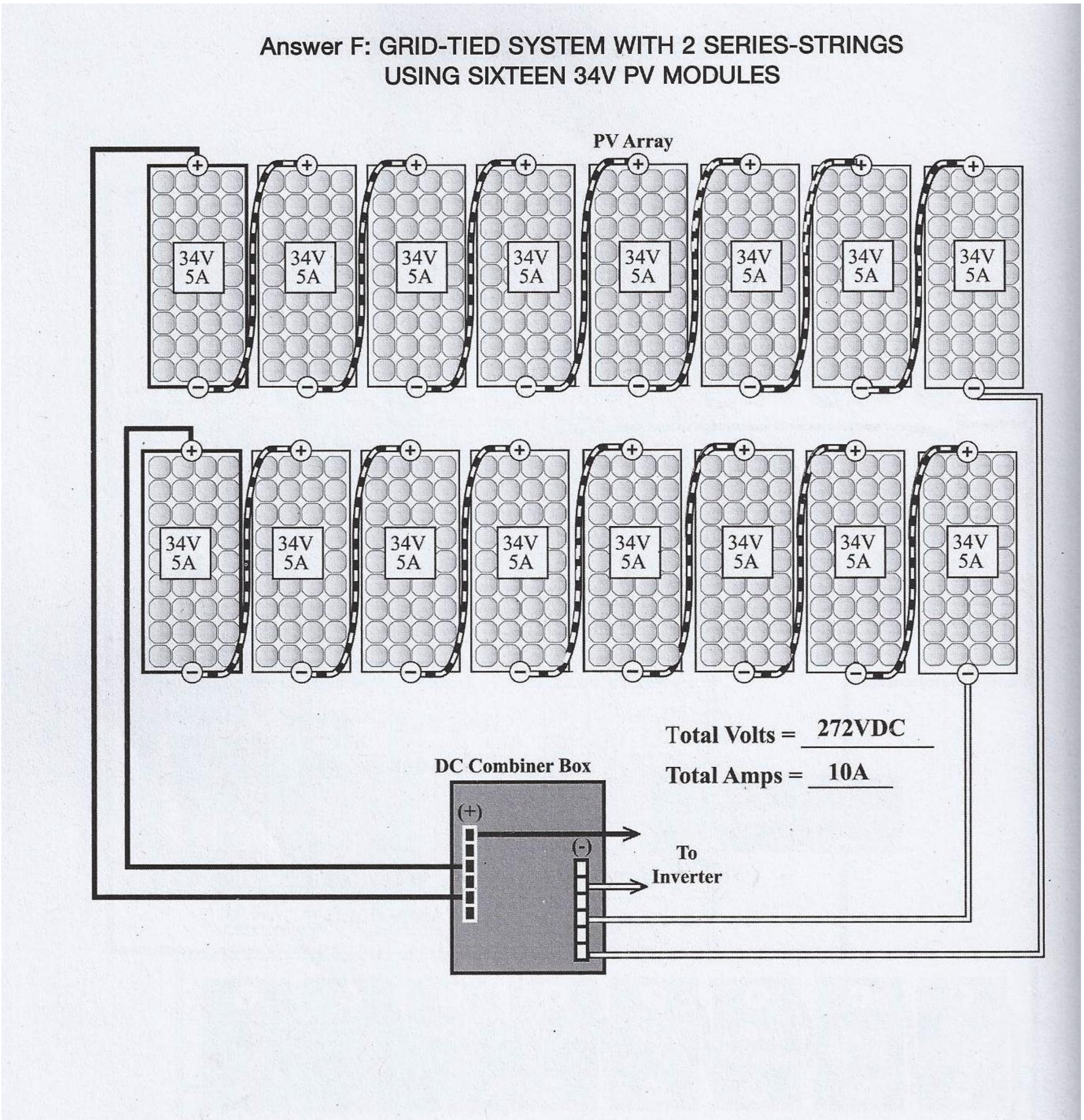
Battery Storage

Answer E: 48V SYSTEM WITH SIXTEEN 12V PV MODULES



Exercise F: DESIGN A GRID-TIED SYSTEM WITH 2 SERIES-STRINGS USING SIXTEEN 34V PV MODULES




Answer F: GRID-TIED SYSTEM WITH 2 SERIES-STRINGS
USING SIXTEEN 34V PV MODULES
PV Array
34V
5A
Total Volts = 272VDC
Total Amps = 10A
DC Combiner Box
(+)
(-)
To
Inverter

Appendix I: Solar Energy Systems Terms and Definitions

A

AGM - Absorbed Glass Mat, a sealed battery that uses saturated absorbed glass mats rather than a gelled or liquid electrolyte between the plates. AGM batteries are more expensive than gell cell batteries or flooded types, but they have superior performance.

Alternating Current - Electric current in which the current changes direction (polarity) 120 times per second (in the U.S.) and is commonly referred to as 60 Hertz (cycles per second) AC. Many other countries use 50 Hertz as a standard.

Alternative Energy - A popular term for "non-conventional" energy systems usually on a smaller scale and includes solar electric systems, wind generator systems, and small hydro-electric systems.

Alternator - A generator producing AC (alternating current) rather than DC (direct current). Alternators are more efficient than DC generators and in automobiles the alternator output is converted to 12 volts DC using rectifier diodes built into the alternator.

Amorphous Semiconductor - A non-crystalline semiconductor material for solar cells also called thin film. Easier and cheaper to make than crystalline semiconductors for solar cells, but also less efficient.

Ampere - 1 Ampere (Amp) is the amount of current that flows in a circuit at an electromotive force (voltage) of one Volt and at a resistance of one Ohm.

Amp Hour - A measure current over a period of time. 1 amp being used or generated for one hour equals 1 AmpHour.

Angle of Incidence - For solar energy systems, the angle at which direct sunlight strikes the surface of the solar panel relative to perpendicular. Sunlight with an incident angle of 90 degrees is the most efficient.

Angle of Inclination - For solar energy systems, the angle that a solar array is positioned above horizontal. (90 degrees would be vertical). A general rule of thumb is to set the angle of a solar array to the latitude +/- 15 degrees.

Anode - The positive electrode or connection of an electrolytic cell or semiconductor device.

Anti-reflection Coating - A thin coating of a material applied to a photovoltaic cell that reduces the reflection of light striking its surface.

AEER - (Appliance Energy Efficiency Ratings) Operating efficiency of appliances as set by the U.S. Department of Energy guidelines.

Array (Solar) - Any number of solar photovoltaic modules or panels connected together to provide a single electrical output.

Asynchronous Generator - An electric generator that produces alternating current that matches an existing power source.

Autonomous System - A stand-alone power system that has no Utility connection. Most systems are designed for 3 to 5 days of power from batteries without recharging from a solar source or standby generator.

AWG - The abbreviation for American Wire Gauge, a standard system for designating the size of electrical wires.

B

Backup Energy System - A back-up electric power system using batteries and an inverter, an AC generator, or both.

Battery - A device containing electrolytic cells to store electrical energy in chemical form.

Blocking Diode - A semiconductor device used to stop the flow of current from one direction, but allow it in the opposite direction.

British Thermal Unit (BTU) - The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Bus (electrical) - An electrical conductor that serves as a common connection point for multiple connections.

Bypass Diode - A diode connected across a solar cell in a photovoltaic module such that the diode will conduct if the cell becomes reverse biased due to shading or the failure of other cells.

C

Cathode - The negative electrode or connection of an electrolytic cell or semiconductor device.

Cell (battery) - The basic unit of an electrochemical battery. A lead acid cell produces about 2.12 volts and a 12 volt battery uses 6 of these cells and fully charged measures about 12.72 volts.

Cell (solar) - The basic unit of a photovoltaic solar panel. A 12 volt solar panel typically has 36 individual cells, a 24 volt solar panel uses 72 cells.

Charge Controller - An electronic device that regulates the voltage from the solar panel array to ensure maximum transfer of energy and prevent overcharging the battery bank.

Circuit - An arrangement of individual electronic components or devices that use the flow of electrical current thru them to perform useful work or functions.

Circuit Breaker - A safety device used to stop the flow of electricity in an electric device or circuit to prevent damage or fire when an overload condition occurs.

Combiner Box - A solar array junction box where multiple solar modules are electrically connected together and fusing devices may be located.

Conductor - Any material through which electricity can flow. Gold, silver, copper, and aluminum (in that order) make excellent conductors.

Conventional Power - Power generation from sources such as hydro, petroleum, natural gas, coal, or nuclear power plants.

Conversion Efficiency (solar panel) - The ratio of the energy produced by a photovoltaic device to the energy received or consumed expressed as a percentage. Solar panels are typically 9% to 14% efficient.

Converter (DC) - Typically, an electronic device for changing 120 volts AC to lower voltage DC.

Crystalline Silicon Photovoltaic Cell - A type of photovoltaic cell made from a single crystal or a polycrystalline slice of silicon. Individual cells are then joined together to form a solar module.

Current (Electrical) - The flow of electrons in an electrical circuit, measured in amperes (amps).

Cycle (AC) - In alternating current (AC), the current goes from zero to maximum in one direction then zero to maximum in the other direction then repeats. In the United States a complete positive/negative cycle occurs 60 times each second and is known as 60 cycle AC.

D

Deep Discharge - Discharging a battery down to 20 percent or less of its full charge condition.

Diffuse Solar Radiation - Unfocused sunlight scattered by atmospheric particles and arriving at the earth's surface from all directions.

Dimmer (switch/control) - An electronic device that allows light levels to be adjusted from dim to full brightness.

Diode - A semiconductor device that allows current to flow in one direction only.

Direct Current (DC) - Electric current in which the flow of electrons is in one direction only. Opposite of Alternating Current (AC).

Discharge Rate - The rate that energy is removed from a battery, usually expressed in AmpHours.

DOD (Depth of Discharge) - The percentage that a battery is discharged from a fully charged condition.

E

Earth Sheltered Home - A home with large earthen berms around exterior walls to provide wind protection and insulation.

Electrical Grid - An large integrated system of electricity distribution from centralized locations to individual homes and businesses.

Electric Circuit - See 'circuit'.

Electric Current - See 'current'.

Electrolyte - A liquid or gel type conductor of electricity that carries current by the movement of ions (instead of electrons) between the plates in batteries.

Electromagnetic Energy - Energy generated from an electromagnetic field produced by a magnet or an electric current flowing through a conductor.

Electromagnetic Field (EMF) - The electrical and magnetic fields produced by any device operating with electricity.

Electron - An elementary particle of an atom with a negative electrical charge and a mass of 1/1837 of a proton. Electrons surround the positively charged protons in the nucleus of an atom and the number of electrons determine the atomic element. Elements that loose electrons easily make good conductors and elements whose electrons are tightly bound together make good insulators. It is this movement of electrons which is the electric current in circuits.

Electronic Ballast - A high voltage transformer that excites the ions in fluorescent lamps.

Emissions - Substances or by products (usually polluting) resulting from energy production.

Energy Efficiency Ratio (EER) - A measure of the energy efficiency of room air conditioners based on the U.S. Department of Energy guidelines.

Equinox - The two times of the year when the sun crosses the equator and night and day are of equal length, occurring on March 21st (spring equinox) and September 23 (fall equinox) in the northern hemisphere.

F

Filament (tungsten) - A coil of tungsten wire suspended in a vacuum or inert gas-filled bulb. When electricity flows thru the tungsten "filament" it radiates energy in the form of heat and light. This is the basic operation of inefficient incandescent lamps.

Float Charge - The float charging voltage is the voltage required to maintain a battery in a fully charged condition after it has been charged.

Fluorescent Light - An electric lamp using a phosphor coated glass tube that glows when ions in the tube are excited with high voltage electricity. Much more efficient than incandescent type lamps.

Foot Candle - A unit of illuminance equal to one lumen per square foot.

Foot Pound - The amount of work done by lifting one pound one foot.

Fossil Fuels - Fuels such as oil, natural gas, and coal are fossil fuels believed to have been formed in the ground from the decayed remains of plants and animals over millions of years.

Frequency - The number of cycles through which an alternating current changes direction twice each second. In the U.S. the standard frequency for electricity is 60 cycles per second (60 Hertz).

Fuel Cell - An electrochemical device that converts chemical energy directly into electricity.

Full Sun - The amount of energy in sunlight striking the earth's surface at noon on a clear day (about 1,000 Watts per Square Meter).

Fuse - A safety device which stops the flow of electricity to prevent damage and fire under overload conditions. See 'ciruit breaker'

G

Gel Battery - A lead-acid battery in which the electrolyte between the plates is composed of a gelled substance instead of water which is used in automotive batteries.

Generator (AC) - An electric generator driven by a internal cumbustion engine to produce electricity for stand-alone systems and for back-up electrical power. The fuel used may be gasoline, diesel, or propane (LPG).

Gigawatt (GW) - 1,000,000,000 watts, 1 million kilowatts, or 1,000 megawatts.

Green Power - A popular term for energy produced from clean, renewable energy resources such as wind, solar, or hydro electric systems.

Grid - A common term referring to an electricity transmission and distribution system run by large utility companies.

Grid Tie System - An independent electrical power system that is connected to the utility grid so that power can be supplied by the grid when needed and fed back into the grid during excess power production.

Ground - The electrical potential where voltage is zero or at a minimum. Connecting one side of the electric system and metallic surfaces of electric systems to ground potential prevents shocks by bleeding the voltage down to a safe level.

H

Hertz - Short hand for 'cycles per second'. It is the frequency of an AC electric system and is 60 hertz in the U.S.A.

Hybrid System - A renewable or alternative energy system that uses two different sources for power, such as wind generators and solar photovoltaic arrays together to produce electricity.

Hydroelectric Power Plant - A power plant that produces electricity by using water pressure to turn large turbines.

I

Incandescent (lamp) - A fairly inefficient type of lamp that uses a wire filament suspended in a vacuum or inert gas-filled bulb that give off heat and light when electricity flows thru the filament.

Infrared Radiation - Electromagnetic radiation below the visible range. Also known as heat radiation.

Inverter (AC) - An electronic device that converts 12, 24, 48, or higher volts DC power from batteries or solar panels to 120/240 volts AC to operate normal appliances.

K

Kilowatt (KW) - A standard unit of electrical power equal to 1000 watts.

Kilowatt-Hour (KWH) - 1000 watts produced or consumed for a period of 1 hour.

L

Lead Acid Battery - An electrochemical battery that uses lead and lead oxide for electrodes and sulfuric acid for the electrolyte. When the sulfuric acid is mixed with water, it is known as a flooded battery. Batteries whose electrolyte is a gel or absorbed glass mat type are called sealed batteries. Not to be confused with sealed batteries, a maintenance-free battery simply has no way to add water and when low is just discarded.

Line Loss - Energy lost due to inherent inefficiencies in an electrical transmission and distribution system.

Load - The devices and appliances that draw power from an electrical supply system.

Long-Wave Radiation - Infrared or radiant heat energy.

Luminance - The measure of the apparent brightness of an object, measured in lumens.

M

Maximum Power Point (MPP) - The point on the current-voltage (I-V) curve of a solar panel, where the product of current times voltage equals maximum wattage.

Maximum Power Point Tracking (MPPT) - A charge controller technique that attempts to supply maximum power to the batteries by tracking the maximum power point (MPP) at all times achieving a 15% to 35% increase over other types of charging techniques.

Megawatt - 1 million watts or 1 thousand kilowatts (1,000,000 watts).

Megawatt-Hour - 1 million watts produced or used for a period of 1 hour.

Module (solar) - A number of individual solar cells connected together in an environmentally protected housing producing a standard output voltage and power. Multiple modules/panels can be assembled into an array for increased power and/or voltage.

Monolithic - Manufactured or assembled as a single structure.

Monocrystalline - A material used in solar cells that uses a complicated crystal growth process. Long silicon rods are produced which are cut into slices of .2 to .4 mm thick discs or wafers which are then processed into individual cells.

Motor Speed Control - An electronic device that manually or automatically varies/controls motor speed as in a multi-speed fan.

Multicrystalline - A material composed of randomly oriented, small individual crystals. (Sometimes referred to as polycrystalline or semicrystalline).

N

Name Plate - An identifying tag usually located near the AC cord of an appliance that contains information such as model number, serial number, operating voltage, and power consumption.

National Electrical Code (NEC) - The NEC is a set of regulations and standards that most electrical equipment installations must follow making the electrical system in the United States one of the safest in the world.

Net Metering - Using a single meter to measure usage and generation of electricity by customers with a wind or solar power energy system. The net energy used or produced is either purchased from or sold to the power company.

O

Off-Peak (demand)- The times during a 24 hour period of low electricity demand. Opposite of peak-demand.

Ohm - The unit of resistance to the flow of electrons in an electric circuit.

Ohm's Law - The various formulas that define the relationship between resistance(R), voltage(E), and current(I) as in E=I*R, I=E/R, R=E/I, etc.

One-Axis Tracking - A solar tracking system that moves in only 1 direction or axis generally following the sun in its arc across the sky from east to west.

Open-Circuit Voltage (Voc)- The maximum possible voltage across a photovoltaic cell or module in sunlight when no current is flowing.

Ovonic - A device (solar cell) that converts sunlight directly into electricity, invented by Standford Ovshinsky.

P

Panel (Solar) - A solar photovoltaic device composed of groups of individual solar cells connected in series, in parallel, or in series-parallel combinations to produce a standard output. See 'module'.

Parallel - A wiring technique where multiple devices are wired together to increase current but voltage remains the same.

Payback Period - The amount of time required before the savings resulting from an energy producing system equals the cost of the system, typically 5 to 10 years. This number has been steadily decreasing as alternative energy systems become more popular and more practical.

Peak Sun Hours - The equivalent number of hours per day when solar radiation averages 1 KiloWatt per square meter. For example, 5 peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the solar radiation for 5 hours been 1 KiloWatt per square meter.

Peak Watt - The maximum nominal output of a PV (solar) device, in Watts (Wp) under standardized test conditions. (usually the most favorable!).

Phantom Load - The small power used by an appliance even when it is turned off. Examples of phantom loads include appliances with electronic clocks or timers and devices with remote controls whose circuits remain active in order to detect the remote control signal to power up.

Photon - A particle of light that acts as an individual unit of energy.

Photovoltaic Array - A group of solar photovoltaic modules connected together to increase voltage and/or power to the level required for a given system.

Photovoltaic Cell - Specially processed semiconductor materials such as silicon, cadmium sulfide, cadmium telluride, and gallium arsenide that convert sunlight directly into electricity. Three common types are mono-crystalline, multi-crystalline, and amorphous/thin film.

Photovoltaic Conversion Efficiency - The ratio of the energy produced by a photovoltaic device to the energy received or consumed expressed as a percentage. Solar panels are typically 9% to 14% efficient.

Photovoltaic Module or Panel - See 'module' or 'solar module'.

Poly-crystalline - A semiconductor (photovoltaic) material composed of randomly oriented, small, individual crystals.

Power - Useful energy that performs work measured in horsepower, Watts, or Btu's. Electrical power is rated in Watts and is equal to the Voltage(E) times the Current(I). As in P=E*I.

R

Radiation - The transfer of heat energy through matter or space by means of electromagnetic waves.

Reflective Glass - A window glass that has been coated with a reflective film to reduce unwanted solar heat gain during the summer.

Renewable Energy - Energy from sources that are not easily depleted such as moving water (hydro, tidal and wave power), biomass, geothermal energy, solar energy, wind energy, and energy from solid waste treatment plants.

Resistance (electrical)- The inherent characteristic of a material to inhibit the flow of electrons producing heat in conductors, devices, or components and is measured in Ohms.

Resistor - An electrical device that resists the flow of electrons in electric circuits.

Ribbon Cells (Photovoltaic) - A type of solar photovoltaic device made by pulling material from a molten bath of photovoltaic material, such as silicon, to form a thin continuous sheet of material.

S

Safety Disconnect - A switch that disconnects one circuit from another circuit to isolate power generation or storage equipment from each other.

Self Discharge (rate) - The rate at which a battery, without being used will lose its charge over time.

Semiconductor - Any material that has a limited capacity for conducting an electric current. It is neither a good conductor nor a good insulator. This characteristic allows it to perform controlled operations as transistors, diodes, and integrated circuit packages. Semiconductor material can be densely packed and layered thru photographic processes and has given rise to the modern world of electronics. Certain semiconductors, including silicon, gallium arsenide, copper indium diselenide, and cadmium telluride, are uniquely suited to the photovoltaic conversion process.

Series - A wiring technique where multiple devices are wired together to increase voltage but current remains the same.

Shallow Cycling - Allowing a battery bank to only loose 20% of its full charge when being used, then recharging back to full charge. With a large bank of batteries, this technique can supply sufficient power between charge cycles and will greatly increase the life and performance of the batteries.

Short Circuit - A generally unwanted condition where maximum current flows freely through an external circuit that has no load or resistance, usually due to the catastrophic failure of a device or component.

Silicon - A chemical element, of atomic number 14, that is semi-metallic, and an excellent semiconductor material because the atoms in the outer shell are neither tightly bound nor loosely bound to the nucleus.

Sine Wave - The wave generated by alternating current generators and sine wave solid-state inverters.

Single-Crystal Material - See 'monocrystalline'.

Sizing - The process of designing a solar electric system to meet the required operating loads based on the total wattage of all appliances in the system.

Solar Array - See 'Photovoltaic Array'.

Solar Cell - The basic unit of a photovoltaic solar panel. A 12 volt solar panel typically has 36 individual cells, a 24 volt solar panel uses 72 cells.

Solar Constant - The average amount of solar radiation that reaches the earth's upper atmosphere on a surface perpendicular to the sun's rays; equal to 1353 Watts per square meter or 492 Btu per square foot.

Solar Energy - Electromagnetic energy transmitted from the sun (solar radiation). The amount that reaches the earth is equal to one billionth of total solar energy generated, or the equivalent of about 420 trillion kilowatt-hours.

Solar Module (Panel) - A number of individual solar cells connected together in an environmentally protected housing producing a standard output voltage and power. Multiple modules/panels can be assembled into an array for increased power and/or voltage.

Solar Noon - The time of the day, at a given location when the sun reaches its highest point in the sky.

Solar Radiation - The various wavelengths of electromagnetic radiation that is emitted by the sun including the visible light we can see.

Solstice - The two times of the year when the sun is apparently farthest north and south of the earth's equator occurring on or around June 21 (summer solstice) and December 21 (winter solstice) in the northern hemisphere.

Square Wave Inverter - A type of inverter that produces square wave output. The square wave inverter is the simplest and the least expensive to purchase, but it produces the lowest quality of power.

Stand-Alone Inverter - An inverter that operates independent of any utility company grid or electric transmission and distribution network.

Stand-Alone System - An system that operates independent of any utility company grid or electric transmission and distribution network.

Stand-By Power - See 'Phantom Power'.

State of Charge (SOC) - The remaining charge available in a battery, expressed as a percentage of the battery when fully charged.

Synchronous Inverter - An inverter that produces alternating current electricity from direct current electricity and uses another alternating current source, such as the electric power grid or a generator to synchronize its output voltage and frequency to the external power source.

T

Thin-Film - A layer of semiconductor material a few microns or less in thickness, used to make solar photovoltaic cells.

Tilt Angle (of a Solar Array) - The angle at which a solar array is set to face the sun relative to a horizontal position and is usually adjusted seasonally due to the changing declination of the sun.

Tracking Solar Array - A solar array that follows the path of the sun during the day to maximize the solar radiation it receives. A single axis tracker tracks the sun east to west and a two-axis tracker tracks the daily east to west movement of the sun and the seasonal declination movement of the sun.

Transformer - An electromagnetic device that changes the voltage of AC up or down. It consists of an induction coil with an iron core and a primary and secondary winding, the ratio of which determines output voltage versus input voltage.

Trickle Charge - The small charging voltage required to maintain a battery in a fully charged condition after it has been charged.

U

Ultraviolet Radiation- Electromagnetic radiation ranging from 4 to 400 nanometers in wavelength.

Utility Company - Do we have to spell it out for you?

V

Visible Radiation - The visible portion of the electromagnetic spectrum ranging from 0.4 to 0.76 microns in wavelength.

Volt - A unit of electrical measurement. One volt will cause a current of one ampere to flow through a resistance of one ohm.

Voltage - The difference in electrical potential that exists between two points in a circuit measured in volts.

W

Wafer - A thin section of semiconductor material made by slicing it from a single crystal or rod.

Watt - The unit of electric power in a circuit. One watt equals one ampere under an electrical pressure of one volt.

Watt-Hour - 1 watt produced or consumed for a period of 1 hour.

Wattmeter - A device for measuring power production or usage displayed in watts.