World Focus 1412 CC: Reg No: 2007 / 000484 / 23.
31 Bright Street. **Ph: 021 851 7713.**
Somerset West. **Fax: 086 502 2249.**
7130. **E-mail: info@solarflex.co.za.**

The following is a collection of general information on solar panels and their installations – if you have not worked with any solar panels it will help you to get familiar with what will be required.

Acknowledgements:
The following information is mostly from an American Tutorial Website, with some modifications for the South African recreational market - more info at:
http://www.freesunpower.com

Please note:

- Some information refers to Fahrenheit temperatures and not Celsius, as well as feet and not metres.
- The following refers to general solar power applications, for the 12v applications inverters are not a prerequisite.
- Inverters are only required when it is necessary to power 220volt appliances.

Standard 4x4 or yachting applications require lower quantities of power, the main criteria being:
How many watts or amps per hour do I need to get the job done?

Disclaimer:
The following is a guideline only – please ask your nearest professional installer or qualified electrician for specifics when installing Solar Panels, either for recreational or home power puposes.

1. Components.

The first component needed is one or more Solar Panels. They supply the electricity and charge the batteries.

The 3 Basic types of Solar Panels.

1. **Monocrystalline solar panels** : The most efficient 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.

2. **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.

3. **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.

Charge Controller.

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.

Inverters.

The Power Inverter is the heart of the system. It makes 220 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.

For 12v applications an inverter is not required.

An inverter should only be required when it is necessary to convert the 12v input to power a 220v standard application.

Batteries.

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 is shining or the generator is running.

To summarize, there are four basic components: the Solar Panels, a Charge Controller, a Power Inverter, 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.

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2. Batteries info:

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.

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) 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) 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) 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.

Industrial strength : Flooded, Gel, and AGM sealed batteries

As a technician, 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 fully 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. 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 covers the various configurations for wiring multiple batteries together to obtain increased current capacity (power) and also different voltage configurations.

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.

3. Wiring Info.

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.

Total Amps = Down Column
Wire Gauge = Top Column across.
Distances in table in feet.

		#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

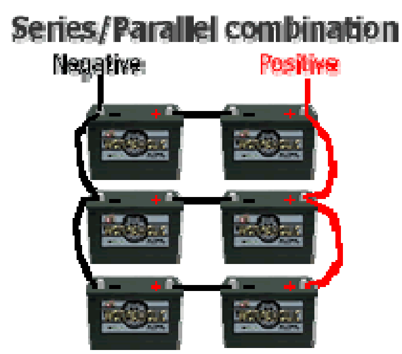
After you connect the Solar Panels to the input terminals of the Charge Controller using the above chart, you can use the same size wire to connect the Charge Controller output to the batteries since these wires will carry no more current than the solar panel wires and will probably be located pretty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



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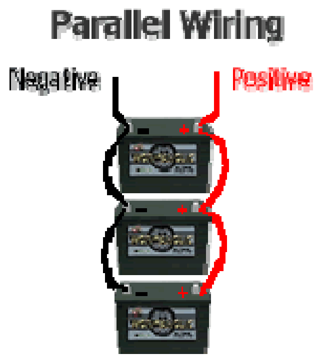
4. Options of Wiring Batteries.

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

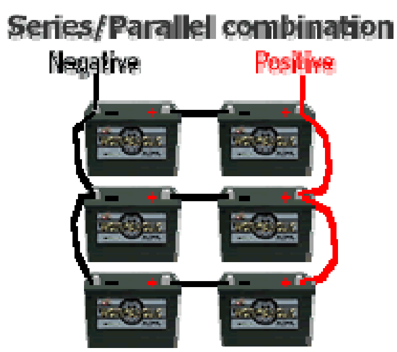
This diagram shows a simple series circuit to increase the battery voltage level. Assume that we are using really big 4 volt industrial batteries.

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.

5. Charge Controller.

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

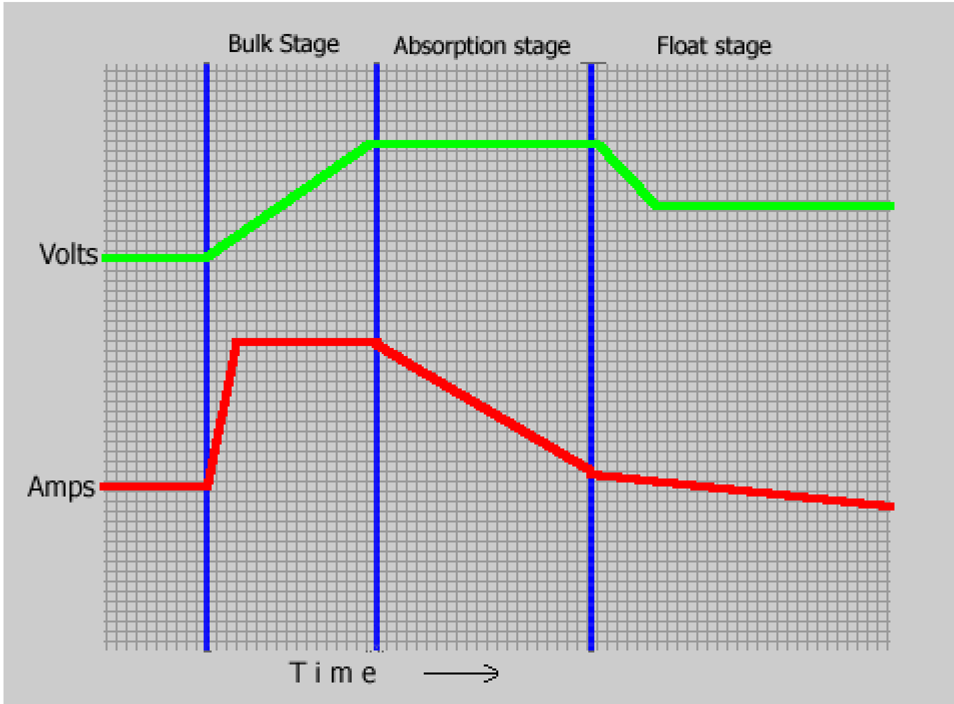
Most quality charge controller units have what is known as a 3 stage charge cycle that goes like this :

1) 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) 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) 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 are Pulse Width Modulation (PWM) types. I would recommend using one of at least this design. The newer Maximum Power Point Tracking (MPPT) controllers are even better. 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 decribed. 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.

6. Terms and 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).

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:

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

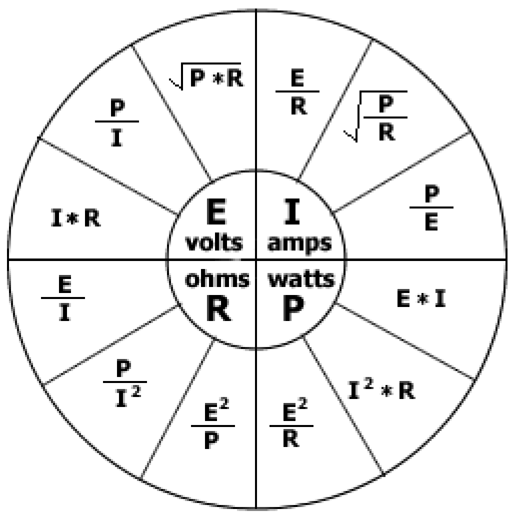
Also, the power can be expressed as $P=E*I$ and with a little algebra we can combined these expressions and derive $P=E^2 / R$

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.

The upshot of all this is twofold:

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.

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7. Inverters.

The Power Inverter

Unless you plan on using battery power 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 :

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 :

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 :

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.

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.

To help decide on which voltage to use, check out our Wire Size Calculator 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.

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 for more info on the necessary wire size for installing one or use our new Wire Size Calculator. 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.

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

The Wires & Cables tutorial 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.

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8. Nice but not essential.

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 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

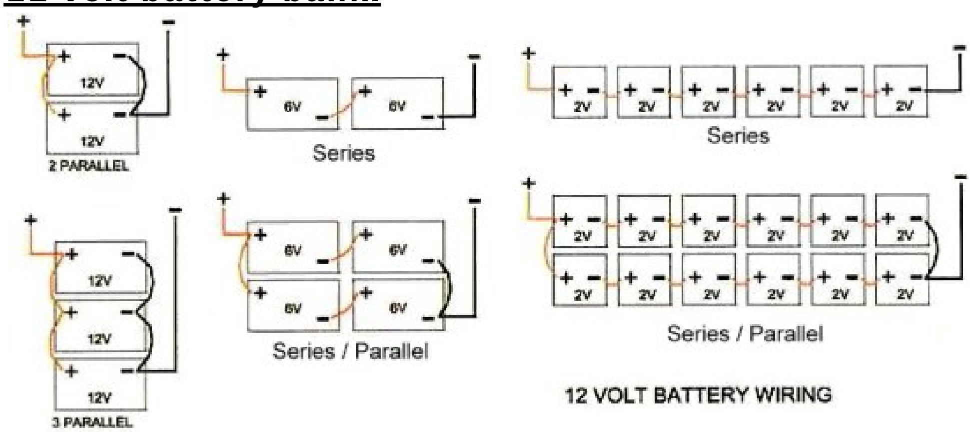
% of Full Charge	Voltage
100 % charged	12.7 volts
90 % charged	12.6 volts
80 % charged	12.5 volts
70 % charged	12.3 volts
60 % charged	12.2 volts
50 % charged	12.1 volts
40 % charged	12.0 volts
30 % charged	11.9 volts
20 % charged	11.8 volts
10 % charged	11.7 volts
completely discharged	11.6 volts or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

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

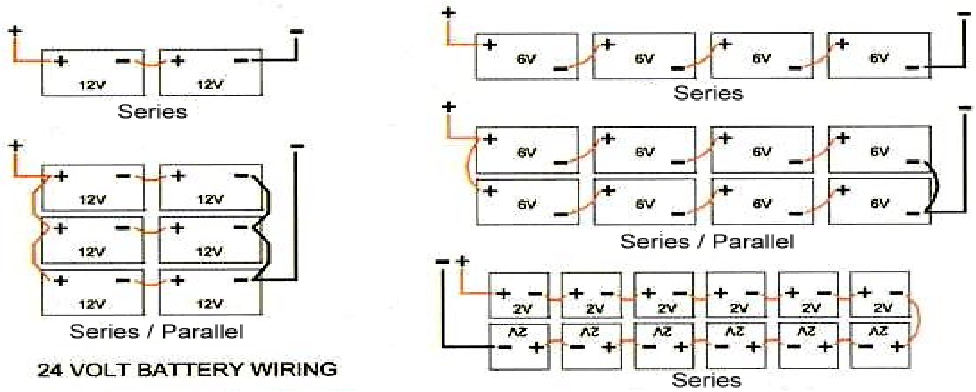
So how much can I expect to pay for a multi-function monitor?

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.

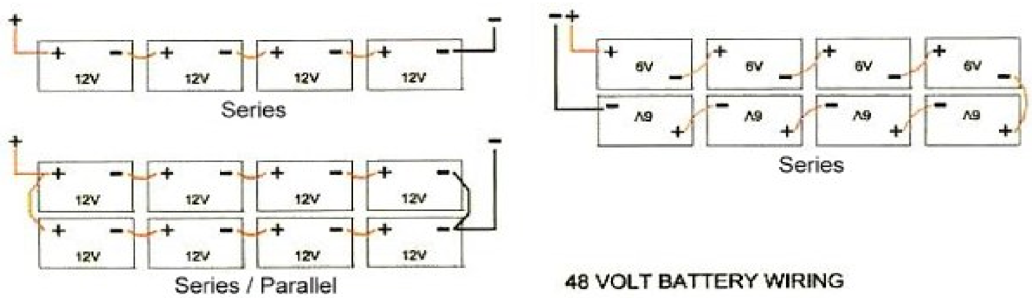
9. 12 volt battery bank.



24 volt battery bank.



48 volt battery bank.



Typical drawing – includes a generator which you may not require.