LSE

Solar India

Solar Power Plant Basics

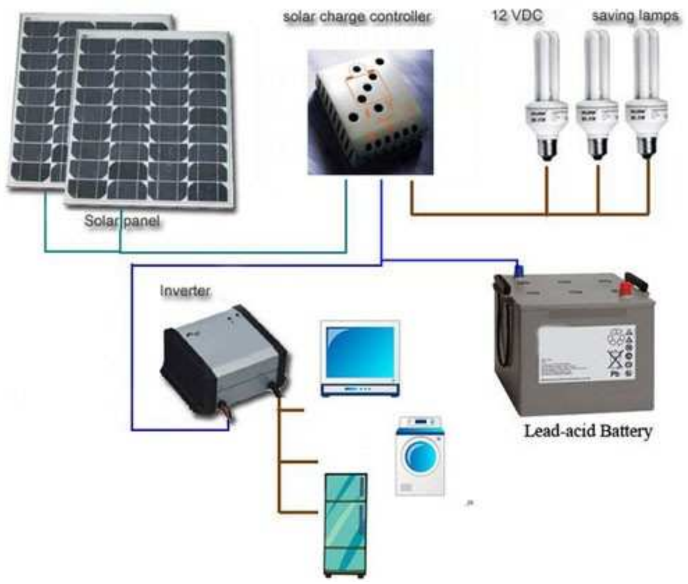
LONGMAN SUNTECH ENERGY

Accelerating the Adoption of Solar Power in India

CONTENTS

OVERVIEW

A Solar Energy System is sometimes referred to as an Alternative Energy 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 “Designing a solar power system” to calculate how many solar panels and storage batteries you will need, what configuration inverter and charge controller to used and determine proper wire sizes.



The first component is a Solar Panel array (Term for a bunch of Solar panels). They generate power from sunlight in DC form.

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 converts the DC output from the Solar panel array or the batteries to AC. This AC power is then used power the load connected to it or supplied to the grid (if provisions for the same are in place. It can also charge the batteries from the Grid or generator when solar output is low or nil.

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.

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 may vary widely from as little as XXXX to XXXX or more.

SOLAR PANELS

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 an electric solar energy 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. The advantages of using a higher voltage output at the solar panels are –

- Reduced transmission or ohm losses
- Reduced wiring cost as smaller wire sizes can be used to transfer the electric power from the solar panel array to the charge controller & batteries.

TYPES OF SOLAR PANELS

The 3 basic types of Solar Panels

MONOCRYSTALLINE SOLAR PANELS

Solar cells made of Monocrystalline silicon (mono-Si), also called single-crystalline silicon (single-crystal-Si), and are quite easily recognizable by rounded edges as well as an external even coloring, and uniform look, indicating high-purity silicon, as seen in the picture to the right. Monocrystalline solar panels have the highest efficiency rates (15% - 20%) since they are made out of the highest-grade silicon. These solar panels also live the longest.

Most solar panel manufacturers put a 25-year warranty on their Monocrystalline solar panels.

However, Monocrystalline solar panels are the most expensive. Monocrystalline solar panels tend to be more efficient in warm weather. Performance suffers as temperature goes up, but less so than polycrystalline solar panels. For most homeowners temperature is not a concern.

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. Unlike Monocrystalline-based solar panels, polycrystalline solar panels do not require the Czochralski process. Raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers. This is what gives them that striking shattered glass appearance. These solar panels are clearly identifiable with the perfect squared square cells as shown in the picture to the right.

The efficiency of polycrystalline-based solar panels is typically 13-16%.

Thin Film solar panels

Depositing one or several thin layers of photovoltaic material onto a substrate is what makes thin-film solar cells (also known as thin-film photovoltaic cells (TFPV). The different types of thin-film solar cells can be categorized by which photovoltaic material is deposited onto the substrate

- Amorphous silicon (a-Si)
- Cadmium telluride (CdTe)
- Copper indium gallium selenide (CIS/CIGS)
- Organic photovoltaic cells (OPC)

Depending on the technology, thin-film module prototypes have reached efficiencies between 7–13% and production modules operate at about 9%. Future module efficiencies are expected to climb close to the about 10–16%. They are easier to mass-produce and potentially cheaper to manufacture than crystalline-based solar cells. Their homogenous appearance makes them look more appealing. They can be made flexible, which opens up many new potential applications.

AMORPHOUS SILICON (A-SI) SOLAR CELLS

Solar cells based on amorphous silicon have traditionally only been used for small-scale applications such as in pocket calculators, because the output of electrical power is low, However, recent innovations have made them more attractive for some large-scale applications too.

With a manufacturing technique called “stacking”, several layers of amorphous silicon solar cells can be combined, which results in higher efficiency rates (typically around 6-8%).

CADMIUM TELLURIDE (CDTE) SOLAR CELLS

Cadmium telluride is the only thin-film solar panel technology that has surpassed the cost-efficiency of crystalline silicon solar panels in a significant portion of the market (multi-kilowatt systems).

The efficiency of solar panels based on cadmium telluride usually operates in the range 9-11%.

COPPER INDIUM GALLIUM SELENIDE (CIS/CIGS) SOLAR CELLS

Compared to the other thin-film technologies above, CIGS solar cells have showed the most potential in terms of efficiency. These solar cells contain less amounts of the toxic material cadmium that is found in CdTe solar cells. Commercial production of flexible CIGS solar panels was started in Germany in 2011.

The efficiency rates for CIGS solar panels typically operate in the range 10-12 %.

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 will shading of the solar panels significantly reduce their output, but also could cause damage. Some solar panel manufacturers advertise panels that can withstand shading but they use internal diodes which in themselves reduce the power somewhat. I recommend simply choosing 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.

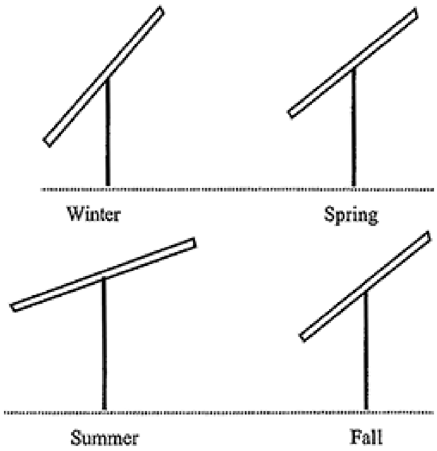
TILT & TYPE OF ARRAY MOUNTINGS: FIXED, ADJUSTABLE, & TRACKING

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. 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.

Adjustable solar panel mounts

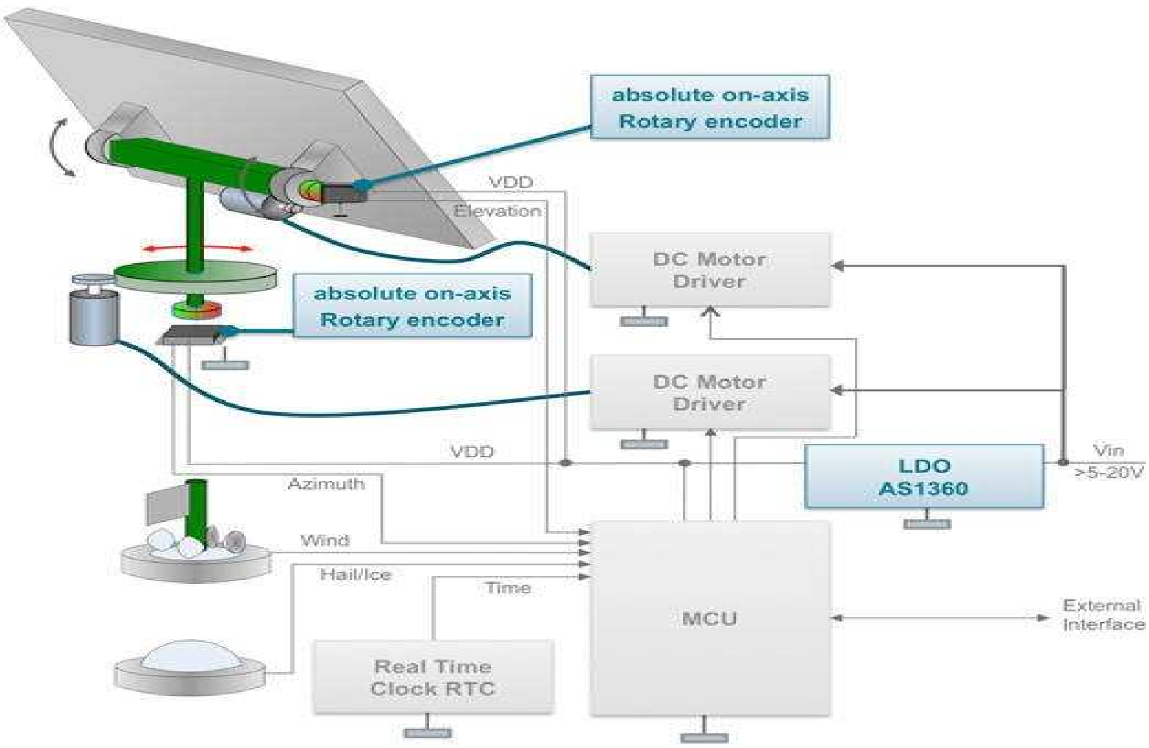
The angle of inclination (tilt) of an adjustable solar panel mount can be changed 2 or more times during the year to account for the lower angle of the sun in winter as the earth orbits the sun causing seasonal change. A good rule of thumb is latitude + 15 degrees in the winter and latitude - 15 degrees in the summer. This will increase overall solar panel output by approximately 25%. An easy approach that works pretty well 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.

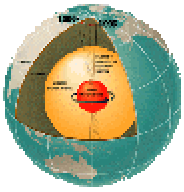
A tracking type of solar panel mount is the most efficient type. However on investigation, it’s been found that for the 20 to 30 percent gain in output they provide one could buy 25% more panels cheaper and have the same increase in power with no mechanical failures to worry about. Also, you'll get far less extra gain in winter assuming it doesn't freeze up!



ORIENTATION

The solar panels should always face the equator, i.e. due south in the northern hemisphere & due north in southern hemisphere. Assuming our installations will stay mostly in the northern hemisphere, our solar panel arrays should be facing true south. Now, true south varies from magnetic south. This deviation is technically known as declination. Please use the link below to webpage, which will let you enter your co-ordinates and show you the resultant declination.

http://www.ngdc.noaa.gov/geomag-web/#declination



A point to remember is that the resultant declination is not constant and varies on a yearly basis. This is owing to the simple reason that the earth's magnetic core is rotating with respect to the outer shell and in-fact turns over a full 360° in 100,000 years.

SOLAR RADIATION DATA

Solar Radiation data is made available in 2 different versions. Both the versions are expressed in kWh/m^2/day. Both radiation data versions for India are made available for solar power system installers on the MNRE website: http://mnre.gov.in/sec/solar-assmnt.htm under the tag Solar Radiation Data towards the bottom of the page. This data has also been downloaded and can be accessed by LSE personnel on request. These two data versions are as listed below

- DNI – Direct Normal Irradiance: This data is a measure of direct normal radiation that an area receives and is useful for Solar CSP (Concentrated Solar Power) installation.
- GHI – Global Horizontal Irradiance: This data is a measure of DNI + diffused radiation that an area receives. Solar PV (Photo voltaic) installation use GHI instead of DNI, as PV panels are capable of utilizing even the diffused radiation that reaches the earth's surface. This capability of PV panels let them produce electricity also during dusk, dawn and even on a cloudy day when there is no normal radiance from Sun made available on the earth's surface.

AC SOLAR PANELS

All solar panels generate DC power. An AC solar panel is the combination of a solar panel with a pre-installed DC to AC inverter. These inverters are referred to as micro-inverters. They come either pre-installed on a solar panel or are attached to the solar panel on the job site during installation. Because each AC panel is equipped with its own micro-inverter, the disadvantage of voltage drop affecting entire solar array, as it does in centralized inverter systems, is eliminated. Each solar panel can work independently to produce its maximum power in all conditions. The disadvantage of possible higher initial cost is offset by increased power production from the same modules over time and the ability to monitor output at a single module level.

More manufacturers will produce solar panels with pre-installed micro-inverters giving end users more control and monitoring of their solar investment. Solar panel installation cost will go down with the simplicity of plug and play solar panel micro-inverter systems. Lower installation costs will further push the cost of solar down allowing for deeper market penetration. Current standard DC solar panels will become a specialty item for RV solar, DC off grid cabins and remote telecommunication projects.

SYSTEM SIZING – SOLAR PANEL ARRAY

1. *Calculate the total kilo-watt hours required by your load. Total Kilo-watt hours is the sum-product of wattage (in kW) of all load components & the number of hours that each of these load components need to be powered.*
2. *Multiply the value computed in Step 1 by 1.2 to account for 20% losses in the system.*
3. *Divide this by the effective solar radiation (expressed in **kWh/m²/day**) at your location. This is the required Watt-peak (Wp) rating of the Solar PV array.*
4. *Solar panels come in various Wp rating such as 75, 120, 210, 240, 250 & 270. Choose the most appropriate type and number of modules. The best combination of Wp rating and number would have the sum of Wp ratings of all the panels equal to the "Required Wp rating"*
5. *The next step is Array design. Solar panels connected in series are known as "**Strings**" In a string formation the resultant voltage rating of the string is the summation of the rated voltage of all the Panels whereas the resultant current rating of the string is same that of individual solar panels.*
6. *Size of the String is limited by*
    a. *Max input voltage of the inverter to be used – The V_{oc} (the Open Circuit Voltage) of the resultant Array should be less the max input DC voltage of the Inverter*
    b. *MPP range of the Inverter – Rated voltage of the resultant Array (specified as V_R or V_{MPP}) at the lowest possible temperature measured at the site throughout the year should be less than the upper MPP range of the Inverter. Similarly this rated voltage at the highest recorded temperature should be more than the lower MPP range of the inverter*
    c. *Max Voltage rating of Solar panel – Every solar panel comes with a maximum system voltage that it can handle. The Array voltage at no time should be more than this specified voltage limit*
    d. *Highest efficiency voltage point – Every inverter manufacturer specifies a voltage at which the DC to AC conversion efficiency of the inverter is maximum. It is highly advisable to have the String voltage or Block voltage as close to this figure as possible*
    e. *Max Current or Power rating of the Inverter- It is advisable to also check if the Short circuit current or max rated current of all the strings have exceeded the current rating of the Power Inverter. This check also need to done in case of Max DC power input rating of the Inverter.*
7. *Strings thus designed are connected in parallel and*
    a. *Fed into the Inverter or PCU in case of smaller off-grid or grid ties systems*
    b. *Combined to form what is known as a "**Block**" in case large utility or industrial grade installations with rated output running into MWs.*
    c. *Size of this block is limited by the Max current or Power rating of the Central Inverters in case of utility or industrial grade solar power plants*
8. *It is advisable to have String voltage ratings in case of kWp rated smaller systems in more commercially popular voltage standards of 120V, 240V or even 96V at times. This in many cases are*
    a. *The highest efficiency voltage points for the inverter used*
    b. *Electrical components for these voltage ratings are easily available*

$kWhs_{Load} / (kWh/m^2/day)_{Location} = kWp_{System\ Required}$

$V_{MPP\ Array}$ at Max Temp < $V_{MPP\ max}$ of the INV & $V_{MPP\ Array}$ at Min Temp > $V_{MPP\ min}$ of the INV

$V_{oc\ Array}$ at Min Temp < V_{Max} of the INV & $I_{SC\ Array} < I_{Max}$ of the INV

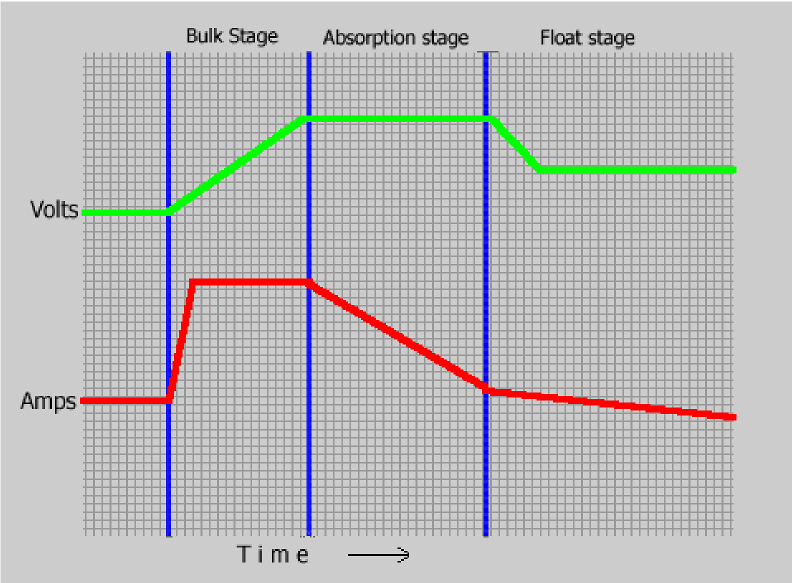
CHARGE CONTROLLER

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 array rises, the charge controller regulates the charge to the batteries preventing any overcharging.

MODERN MULTI-STAGE CHARGE CONTROLLERS: 3 STAGES OF CHARGING

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

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.



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

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 are Pulse Width Modulation (PWM) types. It is recommended that a Solar Power plant uses at least this PWM 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. 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 standalone system, your own AC Generator.

NOTE: If you are using four 75 to 80 Watt solar panels, 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, four 6 amp panels (4*6=24) at times pump out over 32 amps. This is well over their rated 24 amps maximum. For eight 75 to 80 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.

System Sizing – PWM Charge Controller

1. *A PWM charge controller needs to have a voltage rating same as the Solar panel array and the battery bank. This also means that if PWM charge controller is used, all 3 DC components – Solar array, Charge controller and the battery bank needs to operate at the same voltage level*
2. *Determine the maximum amount of current that flows from the Solar array. This is the resultant Isc (Short circuit current) of the Solar panels put in series or parallel*
3. *As a safety margin, multiply the resultant Isc with 1.3*
4. *Choose a charge controller with voltage rating as determined in Step 1 and a current rating equal or more than the current value calculated in Step 3*

System Sizing – MPPT Charge Controller

1. *In case of more intelligent MPPT charge controllers, all 3 DC components can be a different voltage rating.*
2. *Thus the Solar panel array can be set at a higher voltage rating with respect to the battery bank / charge controller. This helps saving of wiring cost as current flowing from the Solar array to the charge controller is low and it's generally the distance between the Solar array and the charger which the max*
3. *So firstly determine the output current of the charge controller. This is the Watt peak rated power output of the system divided by the voltage rating of the battery bank.*
4. *Calculate the resultant open circuit voltage of the Solar array*
5. *Choose an MPPT charge controller with a current rating 1.3 times the current value calculated in Step 3and an upper voltage limit 10% more than the resultant Voc calculate in Step 4*

POWER INVERTER

A Power Inverter converts the DC output of the Solar panel into AC power with required parameters. The Power Inverter will be the heart of your Solar Energy System and in many cases are referred to as a PCU – Power conditioning Unit with its many advanced features. It not only converts the DC power to AC power, but also helps in reducing the harmonics in the system, improving the power factor of the system and charge the batteries from both Solar output as well as the utility grid or the AC Generator connected to the system. Modern day hybrid inverters are also capable of feeing power back to the Grid in case “Net metering” is active in the location under consideration.

TYPES OF POWER INVERTERS

There are majorly 3 types of power inverters used commercially available.

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.

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, it is recommended that this type of inverter is used 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. They are well worth the extra cost. For e.g. A Xantrex 2500 watt power inverter 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, it is recommended that a True Sine Wave inverter is used, as 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.

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 with same voltage rating.

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 installation. The Power Inverter converts the low voltage DC to 120/240 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

System Sizing – Power Inverter (For Off Grid Systems)

1. *Calculate the total wattage of all the load components*
2. *Multiply this wattage figure by 1.3 to obtain a safe kVA rating for the power inverter. This margin of 30% accounts for both the power factor and the voltage fluctuations*
3. *If the load involves components such as pumps, compressors, ACs etc, then account for starting load wattage for those components while doing the calculations in Step 2. As a thumb rule, starting load is generally 2 to 3 times the normal running wattage*
4. *Choose a reliable power inverter with a kVA rating more than what is determined in Step 2.*

System Sizing – Power Inverter (For Grid tie systems)

1. *Choose a reliable Grid-tie inverter with kVA rating equal or more than the resultant kVA rating of the Solar panel array*

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.

BATTERIES

Without batteries to store energy you would only have power when the sun was shining or the generator was running. Firstly, we will discuss the types of batteries and then ponder over some good tips on the care & feeding of your batteries to maximize their performance and life.

TYPES OF BATTERIES

There are 4 basic types of batteries. The first type discussed here is more for pleasure purpose. 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.

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

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 Déjà 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.

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.

AGM

Absorbed Glass Mat batteries are arguably 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

One basic rule is If you are not comfortable, then neither is your equipment here's 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. A 70% range is known to be really good bet for longer life. 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.

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.

Note: Monitoring the Voltage and Current readings in your system will tell you how full your batteries are. Monitoring the Current readings in your system will tell you how fast they are charging or discharging.

All this can be monitored with one or more meters. A solution is to have one meter continuously display the Solar Panels charging current and a multi-function display for Voltage, Amp Hours, and other functions.

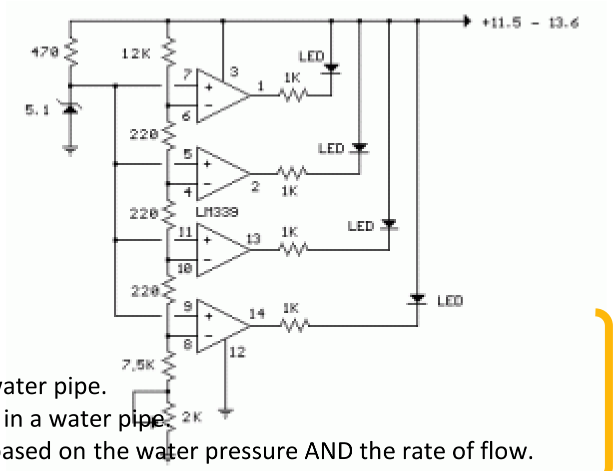
HOW DO I INTERPRET ALL THESE VOLTAGE READINGS?

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.

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

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



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.

will tell you the SOC (state of charge) or simply put how full they are. This measurement is most accurate after the batteries have been at rest at least 1 hour and neither charging nor discharging.

BATTERY CAPACITY

The single characteristic of a battery in which everyone is interested its current capacity unfortunately there is no simple way for a precise calculation or determination of current capacity of a battery. The capacity of a battery is defined by Ampere Hour (AH) which is the product of current in ampere and time in hours.

E.g. A60 AH battery will supply 3 amp. For 20 hours. Normally battery capacity is defined at 20 hour discharge & knows as C20 rating i.e. the capacity will hold well if the battery is discharged in 20 hours. Capacity will reduce if battery is to be discharged at less than 20 hours & will increase if it is discharged at more than 20 hours. Industrial batteries are rated at 10 hour discharge & capacity is known as C 10 rating. A 120 AH battery of C10 rating will deliver 135 AH at 20 hour discharge & 100 AH at 5 hour discharge.

BATTERY BANK DESIGNER

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 these 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.

System Sizing – Battery Bank

2. *Calculate the total watt hours to be consumed by the load. Net Watt hours is the sum-product of wattage of all load components and the number of hours that each of these load components need to be powered*
3. *Decide on the battery bank voltage. Batteries come with rated voltage of 12V or 24V. The battery bank voltage would be a multiple of 12 or 24, depending on voltage rating of the batteries that are used. It is advisable to start with one of the standard battery bank voltages such as 96V, 120V, 180V or 240V*
4. *Find out the number of days of autonomy required. This is basically the time for which the system can provide a back-up. One day of autonomy on Solar parlance refers to 4 to 5 hours after Sunset*
5. *Insert the values calculated in Step 1, Step 2 and Step 3 in the formula below*
6. *Formula -*

$$\frac{Watt\ hours\ required\ X\ Number\ of\ days\ of\ autnomy\ required}{0.85\ X\ 0.61\ X\ Battery\ Bank\ Voltage}$$

7. *The result of this formula would give you the net Ah of the Battery bank required.*
8. *Batteries with C-10 generally come with Ah rating of 150. If the Ah rating calculated in Step 6 is not more than 15% lesser than 150 or any multiple of 150, we have got our battery bank voltage and Ah rating matched almost to perfection.*
9. *If not, then start the process with another Battery bank voltage rating. Insert this voltage rating in the formula in Step 5, with all other parameters remaining the same. Check for the Ah rating that you get for the condition in Step 7.*
10. *If the reworked battery bank voltage rating matches the Step 7, our quest for right voltage and Ah rating ends, otherwise continue with Step 8 until the condition in Step 7 is met.*