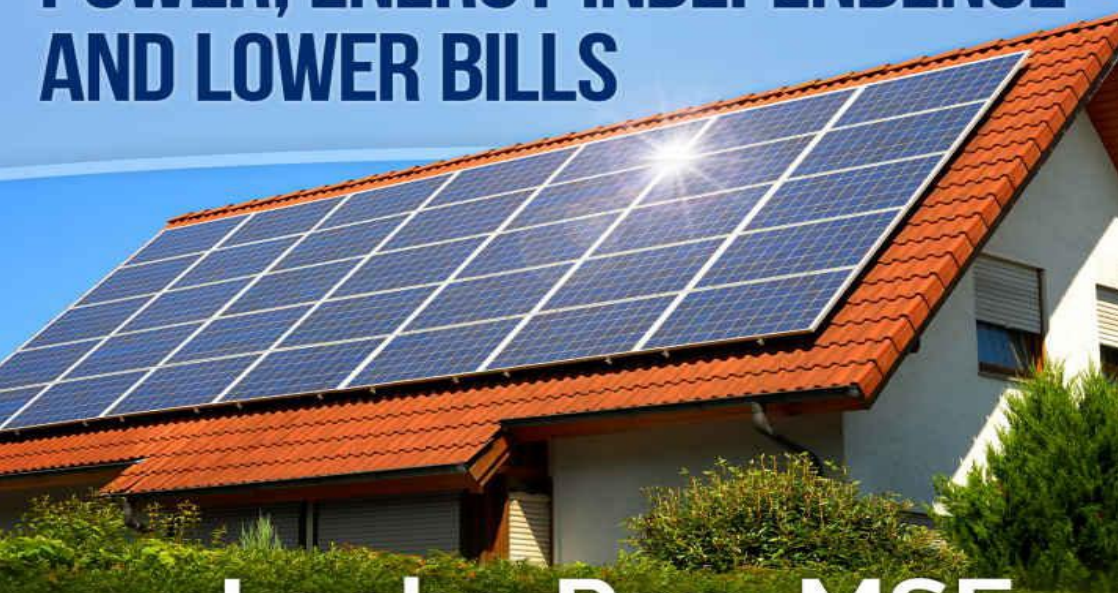
# SOLAR POWER DEMYSTIFIED

## THE BEGINNERS GUIDE TO SOLAR POWER, ENERGY INDEPENDENCE AND LOWER BILLS



By Lacho Pop, MSE
and Dimi Avram, MSE

# Solar Power Demystified

## The Beginners Guide To Solar Power, Energy Independence And Lower Bills


### by Lacho Pop, MSE
### and Dimi Avram, MSE





Published by Digital Publishing Ltd 2019

First Edition – published March 2015

Second Edition – published July 2016

Third Edition – published April 2019

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# Also by the Authors:

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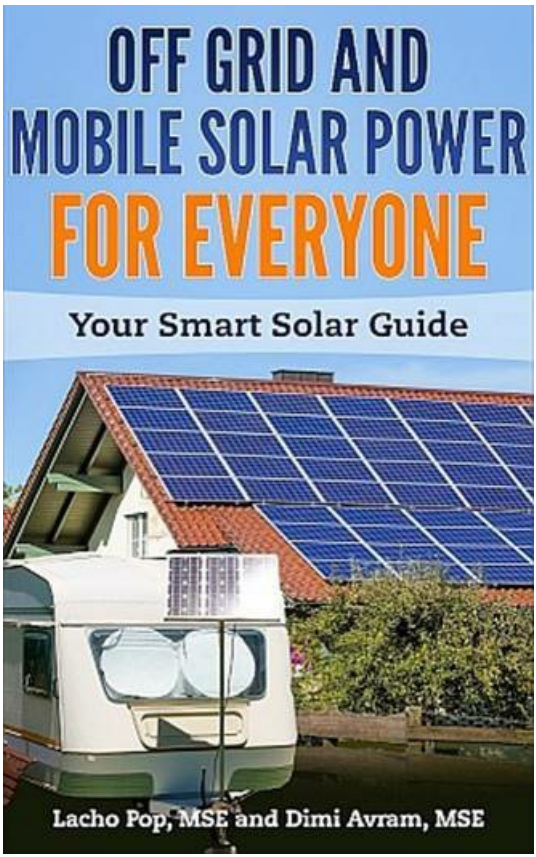


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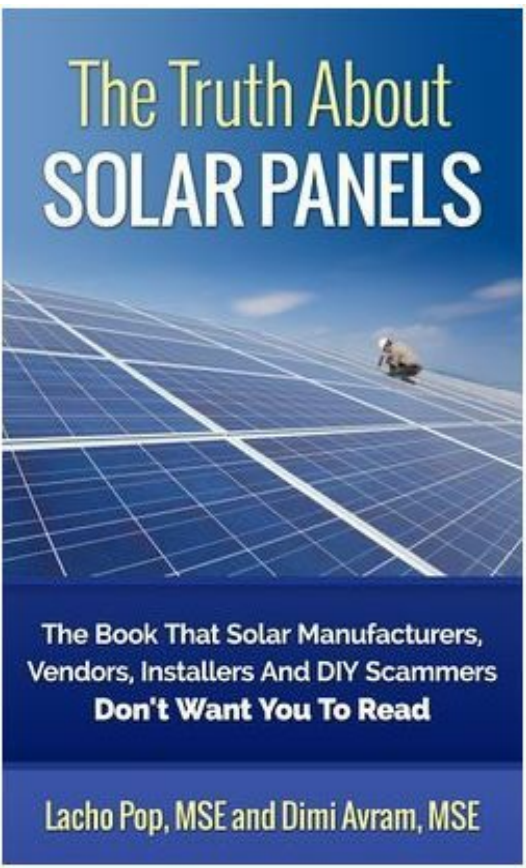


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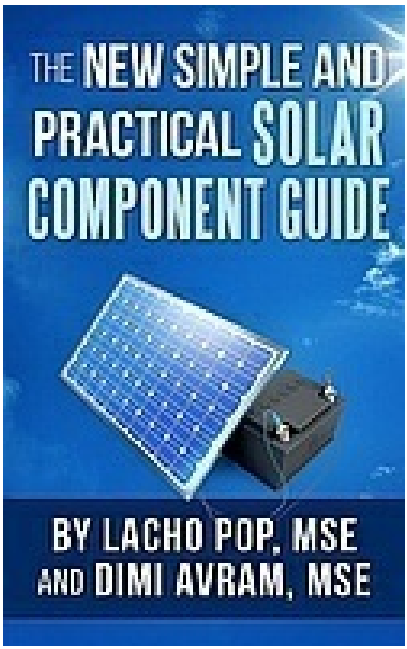


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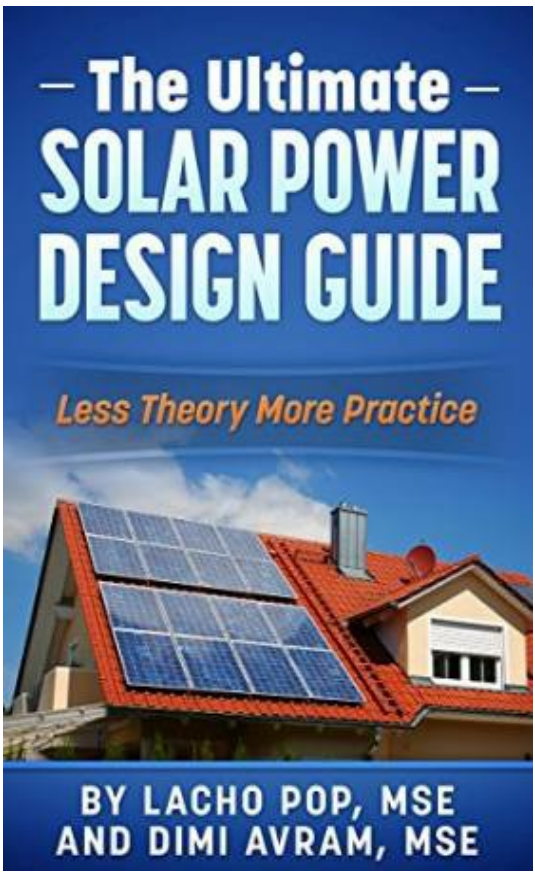


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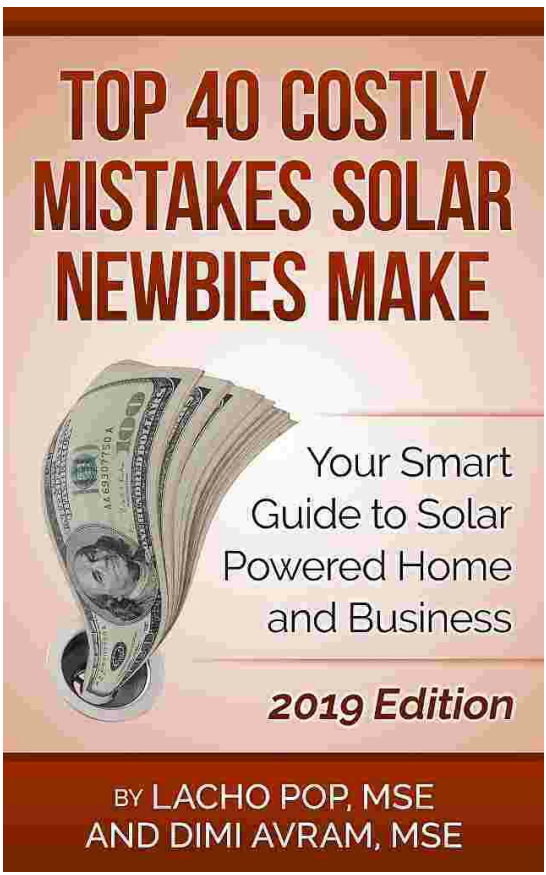


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# Photovoltaics in the world of renewable energy

Solar photovoltaic energy is the energy of the future. It can resolve a lot of the ecological and energy problems of the world.

The energy sources of our planet are running out. Petrol, gas, and coal are available in limited amounts. Utilization of such resources, however, harms the environment – gas emissions of greenhouse effect being the main reason for global warming.

Moreover, the energy consumption is increasing. Till 2030, a 50% increase in energy needs is expected. A possible limitation of electricity consumption would mean deteriorating of lifestyle. Therefore, existing without electrical energy is practically unthinkable.

Besides the problems related to limited amounts of energy resources and ecology issues, many people are experiencing the attitude of brutal negligence and shady pricing policy of local utilities and energy companies. Frequent power outages, continually changing and often incomprehensible tariffs, and pricing of electricity, oil, and natural gas are gradually becoming common. Also, it is proved that utilities have no short-term economic benefit to prevent infrequent large-scale power cuts and cascading failures in power grids. Naturally, they do little to none to improve customer satisfaction in that direction.

What is more, the uncertain geopolitical and ecological situation on the planet forces many people to embrace the idea of self-reliance and seek ways to become more energy independent even at any cost.

In this situation, renewable power sources are the only solution. Solar generators, wind generators, and biofuel products are by all means the Technology of the Future. Utilization of inexhaustible natural resources for energy production is a necessity standing in front of the whole of humanity.

Solar generators

Wind generators

Biofuel products

The sun is an inexhaustible source of energy and can meet the enormous energy demand.

A photovoltaic system located on your roof or near your home is not only going to decrease your dependency on any current and future energy providers but is also going to secure your energy needs.

Photovoltaics can power up reliably RVs, campers, boats thus improving the comfort of their owners.

The long lifecycle of photovoltaic components and the minimum maintenance required for solar systems makes photovoltaics the ideal investment offering users a minimal risk and steady income. Programs for supporting the renewable energy sources, e.g., high purchase prices of electricity and minimal guaranteed terms for buying up the electricity produced, are an additional source of generating profit.

Solar panels are successfully applied upon building façade design by adding modern hi-tech appearance. Photovoltaic panels help contribute to the thermal isolation of buildings and save you expenses for façade tiling. With a solar panel façade, you don't need to repaint a building for at least 25 years!

A solar power system can reasonably increase the cost of your real estate. Such an increase is not only because your home becomes energy-secured, but also because the comfort of living is improved, especially in attics where a solar power installation can act as a conditioner in summer and as a heater in winter.

The need for renewable energy sources coincides with two phenomena – the increasing energy demands and the deposits of coal, oil, and gas, that are gradually running out.

**Advantages of photovoltaics**

**For the user:**

- A well-developed, proven, and reliable technology.
- No moving parts and little maintenance.
- No fuel needed for operation.
- An easy and quick mounting, especially grid-tied systems.
- Off-grid PV systems are capable of producing electricity anywhere in the world.
- Photovoltaic systems generate more energy than they consume – the energy invested in solar panels can be returned in 2 to 7 years, depending on the location and solar system type.
- Photovoltaics add value to the building where they are installed.
- Energy independence.
- Satisfaction from achieving more energy security and bringing family comfort during a power outage.

**For the environment:**

- PV systems help for reduction of carbon dioxide emissions, thus minimizing the greenhouse effect.
- PV systems reduce environmental pollution and do not cause any environmental risks – oil spills, nuclear disasters, global warming.
- PV save the scarce resources available in the bowels of the Earth.
- PV can be recycled – there are various technologies for recycling panels after they are worn out or damaged; solar cells, glass, aluminum frames can be either recycled or reused.

**Why are photovoltaics gaining worldwide popularity?**

- They stimulate sensible and economical energy use.
- They are a popular technology and advertise renewable energy successfully.
- They represent a fast-growing market everywhere in the world.
- The shining of the sun is more reliable and more predictable than the wind. Also, annual values of radiation are relatively constant per given area.
- The energy of the sun is uniformly distributed on the surface of the Earth.
- The solar power technology performs well both in countries located far from the equator and in tropical areas.
- Installation of photovoltaics fosters research and development of a technology of the future.
- Investing in solar power helps achieve energy efficiency and decrease the energy dependence from other countries.

**Why the cost of photovoltaics is decreasing**

The cost of solar power systems is decreasing, and their performance is increasing as a result of:

- Increased efficiency of PV cells and panels.
- Development of thin-film technologies.
- Further development of alternative coatings.
- Improved performance and higher production appliances for crystalline silicon solar cells and panels.
- Improved features and mass production of PV system components.

**Drawbacks of photovoltaics**

**Photovoltaics do have their drawbacks:**

- The overall initial cost of system buying and installation is still high.
- Compared to the efficiency of wind power generators, the efficiency of solar power systems is lower. In other words, the area needed to produce certain power is much larger if you use photovoltaics instead of wind generators.

However, the efficiency of solar panels is not as location-sensitive as in wind turbines. A solar power system can be deployed at almost any place. This is not valid for wind power, however, which is advantageous mostly in coastal areas and areas with relatively high wind speed. Also, thanks to the constantly decreasing prices of solar panels and other components of the solar panel system, solar power gradually becomes competitive with wind power.

- The sun is not always available as a source of energy. This means that for periods of 'sun outage' you need an additional system for electricity storage.

**You can discover more about the disadvantages of solar power on author's blog here:**

https://solarpanelsvenue.com/disadvantages-of-solar-power/

## The main applications of solar power

**Here are the main applications of PV systems:**

- **Water pumping** for small-scale remote irrigation, stock watering, residential uses, remote villages.
- **Lighting** for residential needs, billboards, security, highway signs, streets and parking lots, pathways, recreational vehicles, remote villages and schools, marine navigational buoys.
- **Communications** by remote relay stations, emergency radios, orbiting satellites, cellular telephones.
- **Refrigeration** for medical and recreational uses.
- **Corrosion protection** for pipelines and docks, petroleum and water wells, underground tanks.
- **Utility grids**.
- **Household and RV appliances** – ventilation fans, swamp coolers, TV sets, blenders, stereos, etc.

**Don't go solar before reading this!**

- Solar-generated electricity is still more expensive than the electricity supplied from a utility grid unless you live in a remote area where connecting to a utility grid would cost you a fortune. PV systems make solar electricity more affordable than it was 20-30 years ago, but prices remain relatively high. Nevertheless, in the last few years, prices of solar photovoltaic panels have dropped 80% on average, and they are continuing to decrease.
- Photovoltaic systems are not recommended for heating. For heating, you should use a solar thermal system. Another option is propane or natural gas.
- High costs of PV systems are concentrated in a substantial initial investment. Often the biggest problem is to find initial funding. After you install your PV system, it is nice to feel independent from the utility grid or to see your monthly electricity bills going down. Buying a PV system is actually like paying your electricity bills in advance for years ahead, and the point is to avoid the essential burden of high initial costs. Thus, finding a suitable source of financing is essential.
- Solar electric systems only produce power when the sun is shining. Therefore, something should be done with the electricity produced – it should be either consumed right away, or exported to the grid (in grid-tied systems), or stored in a battery for later use (in off-grid systems).
- For people connected to the grid, usually the decision to purchase a photovoltaic system is based on cost-saving – reducing their monthly bills by selling power to the utility. For people living in remote areas, far from any utility infrastructure, the decision to purchase a PV system is not determined by any cost-saving reasons but is a matter of securing a normal life instead.

# Important:

**If your home is already connected to the utility grid, COMPLETELY replacing the utility with a solar electric system might NOT be cost-effective.**

However, offsetting **a part of** your electrical bills through a solar system can be the best way to save money on electricity.

The utility company's costs for producing electricity are always lower than yours because the utility spreads the costs of generating electricity among its customers.

For this reason, the price you pay for electricity is lower than the price you would pay to have electricity generated by your home solar system. You do pay for generating electricity because, although solar energy is free, PV equipment is not free.

Also, residential PV systems are usually not practical for powering large heating devices – heaters, large electric stoves, air conditioners, or electric clothes dryers.

For this reason, you have to solar-power just the most energy-efficient loads and search for reasonable alternatives for energy non-efficient ('power-hungry') devices.

Moreover, you should start by improving the energy efficiency of your home.

There are national or regional standards, like the National Electric Code (NEC) in the U.S., adopted to ensure safety in all systems that generate, store, transport, and consume electricity.

Your solar power vendor should follow such requirements so that the PV system would be approved by local electric code officials.

Thus, you can expect the price of your property to increase after installing the solar power system.

In many countries, it is required by law that all electrical equipment should be installed by a licensed electrician.

On the other hand, however, many local code officials do not have enough knowledge of PV systems. So even if you follow the rules of the adopted standards, you can have problems to prove to a code official that your solar system is a code-approved one.

It is recommended to contact local code officials and provide them with necessary explanations before you purchase and install a photovoltaic system.

A good plan is to invite them to inspect the installation process before the whole system is completed. This might help your system obtain the needed approval.

If you consider going solar, we highly recommend our book

***'Top 40 Costly Mistakes Solar Newbies Make: Your Smart Guide to Solar Powered Home and Business.'***

The book is available in audio, kindle and paperback format and is targeted to homeowners, RV, boat and business owners who make their first steps in solar power.

Its product identifiers are - Kindle ASIN: B01GGB7QP8, Paperback ISBN-13: 978-6197258073, Audio 2019 Edition ISBN 978-6197258080]

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## *Why energy efficiency comes first*

If you are planning to buy a photovoltaic system, you should start with increasing the energy efficiency of your home or RV.

Achieving energy efficiency means reducing electrical consumption and your monthly electricity bills respectively.

Energy efficiency is vital simply because **saving energy is less expensive than producing energy**. By improving the energy efficiency, the cost of your photovoltaic system is going to be reduced.

You can reduce your electricity use in a variety of ways. You should, however, consider a specific approach and view your home as an energy system comprising various interrelated parts, with each part contributing to the overall efficiency.

**How to improve the energy efficiency of your house or RV**

- Replace incandescent light bulbs, where most of the energy used turns into heat rather than light, with compact fluorescent ones.
- Turn off all stand-by ('phantom') loads, such as DVDs, TV sets, and computers, while they are not in use.
- Upgrade your heating, ventilation, and air conditioning systems.
- Replace your old refrigerator and freezer with new, high-efficiency models (energy-efficient or propane ones).
- Replace high-consumption loads (high-wattage electric stoves, clothes dryers, water heaters, heating appliances) with their propane or natural gas alternative versions. Indeed, a solar thermal water heating system is a perfect option.
- Replace electrical air-conditioning appliances with evaporating cooling systems.
- Make internal isolation of your house.
- Utilize your large electrical loads (pool pumps, electrical mills) during off-peak hours.
- Install solar water heaters and summer shadings.
- Utilize devices with timers and other home automation systems.
- If you live in the U.S., when shopping for electrical appliances, look for devices labeled with Energy Star® label.

## Important:

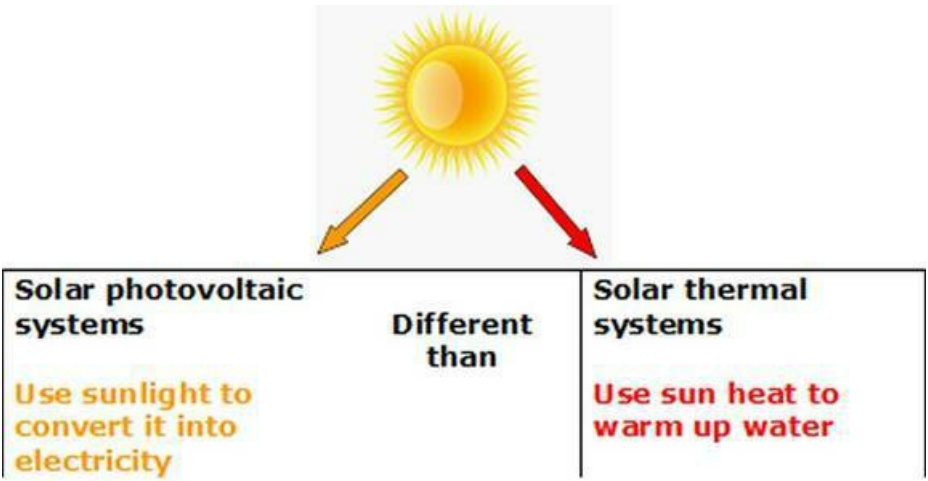
It is not recommended to power electrical heating appliances (dishwashers, washing machines, electrical boilers, tumble driers) by solar-generated electricity. These devices are known as 'power-hungry,' so solar-powering them is going to be very expensive. Therefore, you should find a proper energy-efficient alternative for every heating device.

# The basics of photovoltaics and solar power system components

## *Solar power basics*

A solar photovoltaic system converts sunlight into electricity (electrical energy).

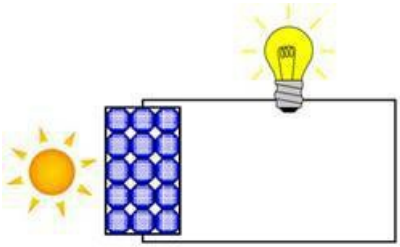
In this book, the terms ‘solar’ and ‘photovoltaic’ are used interchangeably. However, ‘solar’ is also used for solar water-heating systems, which we are not going to discuss here.




A photovoltaic (PV) system can generate a part of or all of your electricity demand.

A PV system can either reduce the amount of power you consume from your utility or replace the grid if you live far from any utility infrastructure.

The main component of a photovoltaic system is the photovoltaic solar panel. A solar panel consists of connected solar cells. Solar panels are connected into solar arrays to achieve higher energy output.



Photovoltaic cells and panels are made of semiconductor material (silicon) capable of producing electricity when exposed to sunlight. Such ability is called 'photovoltaic effect.'

More energy is generated in sunny days, and less energy is generated in cloudy or rainy days, or when the photovoltaic array is shaded by obstructions (trees, buildings, etc.).

Solar panels generate DC electricity (explained further).

The solar-generated power generated can be:

- Used right away,
- Stored in a battery for later use, or
- Converted to AC power, and then either used by electrical appliances or exported to the utility grid.

Solar panels are designed for direct sunlight. Putting a glass between the sun and the panel results in charging the battery three times slower, even in the brightest part of the day (at noon, where the sun is the strongest), compared to when the panels are exposed to direct sunlight.

## *Electricity basics*

Current is a flow of electrons, occurring as a result of a pressure called Voltage. Current is measured in Amperes or Amps (A), while voltage is measured in Volts (V).

On their way through, electrons encounter resistance which controls the current rate. Resistance is measured in Ohms (Ω) and is always related to losses, i.e., due to the resistance the current flow gets weaker. These losses are called 'voltage drops.'

When encounter resistance on its way, however, current is capable of performing work. It's this work that makes electrical appliances operate and serve us. The work performed by the current is called Power and is measured in Watts (W). Another unit of measuring power is kilowatt – 1 kilowatt is 1,000 Watts. Power is a multiple of voltage and current:

**W = V x I**

When the sun is shining, electrons in the solar panels produce voltage and current. This solar-generated current is flowing along wires to the devices and appliances in your home or RV and do some work. This work is the power generated by the solar panel when exposed to sunlight. Each solar panel has its voltage, current and watt ratings printed on its back label.

The work performed for some time is called Energy (E) and is measured in Watt-hours (Wh).

Energy can be either consumed or produced. It is a multiple of power and time, that is, how long this power is used or produced:

**E = W x T**

For example, a 100-watt solar panel produces 100 W of power. For 5 hours of peak sunlight (also known as 'peak sun hours' or PSH), such a panel produces 500 watt-hours (Wh) of energy.

The same goes for the power consumption estimation. For example, a 10W LED lamp operating for 3 hours daily, consumes 30Wh energy per day.

As a solar panel produces power, it's called a generator. Other types of generators are batteries and vehicle alternators. The devices and appliances in

your home or RV consume energy.

Any device or appliance consuming electric power is called a 'load.'

Since **W = V x I**, then **I = W/V**. Thus, you can obtain the current by dividing the watts by the volts. If you, however, divide the energy by the voltage, instead of the power by the voltage, you have:

**C = E/V**

Where C is the energy in Amp-hours (Ah). Amp-hours are used to measure the capacity of a battery. This is the energy drawn or generated by a battery for some time.

For example, if the current rating of your 100-watt panel is 6 amps, for 5 hours you have 6 amps x 5 hours = 30 amps-hours generated. These 30 amps-hours are intended to recharge your battery from which you draw this electricity to power your appliances.

What is the difference between AC and DC electricity?

DC current only flows in a fixed, single direction, or 'forward.' AC current periodically changes its directions – sometimes it goes 'forwards,' but sometimes it goes 'backwards.'

AC electricity is what the local utility grid company provides to our homes is. The AC grid electricity voltage can be 120V or 220 volts. As you know, photovoltaic panels and batteries generate DC electricity. Most of the devices at our home, however, use AC electricity, and unfortunately, we like to use some of them also in our RV. To convert DC electricity into AC electricity, you need an inverter.

The shore power hookups available at most camping sites provide you with AC power. Thus you can power your appliances running on 120/220V AC (120/220V phone chargers, TV, laptops, stereos). To power your 12V DC appliances (lights, water pump, DC fridge), you need a power converter.

If you have a solar array, it usually generates 12V DC voltage. So, you can power your 12V DC appliances, while to power your 120/220V AC appliances you need an inverter (if you don't intend to use a diesel generator). It converts the 12V DC power into 120/220V AC power.

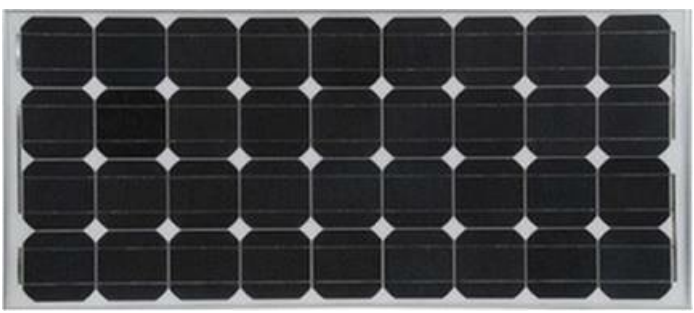
## *Solar (photovoltaic) panels*

### Solar panel types

There are two main types of photovoltaic panels – crystalline and thin-film.

Crystalline panels can be monocrystalline or polycrystalline. A monocrystalline panel is manufactured by a single silicon crystal, while polycrystalline panels are produced by joining many small silicon crystals together. For this reason, these two panel types are very different in appearance, although the surface of both of them is covered with a glass layer.

Monocrystalline panels usually come in black color:



While polycrystalline ones come in bluish color:

Monocrystalline panels are the most efficient, but they are also the most expensive. 'Efficiency' of a panel is the power output provided per unit area of the panel. Thus, apart from their appearance, monocrystalline and polycrystalline panels differ also in their efficiency. For a mobile solar panel system, such a difference is not an issue. However, it cannot be neglected for residential solar systems of medium size, where lots of panels are connected in series and parallel

(explained further).

Thin-film (amorphous) panels are made by amorphous silicon spread on a plastic surface.

Although thin-film panels had a much shorter lifespan in the past, they currently have a life expectancy similar to the crystalline solar panels. Thin-film panels are much cheaper than crystalline ones, but they are also much less efficient – as you usually need a twice larger area to produce the same amount of power by thin-film panels than by crystalline ones.

Solar panels can also be either flat or flexible. Flexible panels can be bent around the curves of your RV, caravan, camper, or boat. Also, they are lighter and more aerodynamic than flat panels, and more expensive. An RV with mounted flexible solar panels on the roof looks more aesthetically. Flat panels, however, are more durable than flexible panels and come with a more extended warranty (25 years of flat panels compared to 10 years of flexible ones). Moreover, flat panels are mounted on a surface in a manner that allows easy cooling underneath. Also, flat panels can be tilted to match the optimal direction towards the sun. Unless aesthetics and improved aerodynamics are of the utmost importance for you, we recommend choosing flat panels for your RV, caravan, or camper.

Flat panels can be monocrystalline, polycrystalline, or thin-film. Flexible solar panels can only be thin-film ones. They are the best option for small mobile solar systems, where you need flexible, small-sized, and lightweight solar panels capable of withstanding physical wear and tear, such as RVs or boats. The more flexible the solar array, the less efficient will it be.

Due to their high reliability, crystalline panels typically come with a warranty of 25 years, which means that they can last much more. Depending on the manufacturing technology, materials used and whether flexible on rigid, thin-film solar panels have a wide range of warranty – from 5 up to 20 years.

Every solar panel has a nominal power rated in watts (W) or kilowatts (kW).

Often, the nominal power of solar panels is denoted in 'watts-peak' (Wp) or 'kilowatts-peak' (kWp). Here is a comparison between solar panel efficiency according to the area needed to install a solar array of 1 kW:

| Solar cell material | Solar panel efficiency | Area need for 1 kW of solar-generated power |
|---|---|---|
| Monocrystalline silicon | 13-16% | 7 $m^2$ (75 sq. feet) |
| Polycrystalline silicon | 12-14% | 8 $m^2$ (86 sq. feet) |
| Amorphous silicon | 6-7% | 15 $m^2$ (161 sq. feet) |

Solar panels differ mostly in their:

- Type – monocrystalline, polycrystalline, thin-film
- Power output – between 10W and 300W
- Output voltage – 12V, 24V, 48V or 60V
- Size and weight – commonly 1.6 x 0.8 meters, or 5.25 x 2.62 feet.

The type and efficiency of the solar panels is not the only factor that determines the performance of your solar panel system. Buying the most efficient (and the most expensive) solar panels does not guarantee that your system will operate at maximum performance. Your target is to get the maximum amount of solar-generated electricity. Thus, your 'homework' is also to consider:

- **Shading** – by any obstacles: trees, buildings, lamp-posts or anything that could prevent the solar panels from getting the full sunlight.
- **Orientation** – this is a primary issue. If you, for example, live in the US, UK, Canada, Europe, or India, your panels should be facing South. If you live in Australia, New Zealand, or South Africa, your panels should be facing North.
- **Tilting** – it is the angle at which the sunbeams hit your panels. The tilt angle comprises two components – the slope of your roof and the tilt angle at which your panels are mounted.
- **Temperature** – in general, high temperatures are not recommended, although thin-film panels, unlike crystalline ones, are more tolerant to heat. High temperatures occur not only during a hot, sunny day but also when there is insufficient space left between the solar panels and your roof for cooling.

**Solar panel voltages**

The **nominal voltage** of a solar panel usually corresponds to the battery voltage for which the panel is designed. Nominal voltage is not the peak voltage of a solar panel. For example, a solar panel can have a nominal voltage of 12V, and its voltage at peak power can be 17-18V. Since a battery needs a voltage of 13.5-14V to be charged, obviously 12V are insufficient, but 17V is okay.

The **maximum power voltage (Vmp)** is the voltage at which a solar panel produces its maximum power under the standard test conditions (STC) (also known as 'maximum power point') while connected to a load. **Vmp** corresponds to the maximum power current (**Imp**) and is always higher than the panel's nominal voltage. A panel of 12V nominal voltage has a **Vmp** between 16V and 18V. **Vmp** and **Imp** are related to the total power and generated by a solar panel for a period of time. The multiple of **Vmp** and **Imp** is the solar panel peak power, sometimes denoted in watts-peak (Wp):

**P (in Wp) = Vmp (in V) x Imp (in A)**

The **open circuit voltage (Voc)** is the voltage measured directly between the positive and the negative terminal of a solar panel with no loads connected. It is the highest voltage a solar panel can produce under certain conditions, that is, the lowest cell temperature. Under the same conditions, **Voc** is always greater than **Vmp**. It is not related to the performance of the solar system and is rather used when sizing some of the system components. The open circuit voltage is different from the maximum power voltage in that the solar panel is not connected to a load.

The **system voltage** is practically the same as the nominal voltage, but while the nominal voltage is used for solar panels, system voltage is used for batteries, charge controllers, and the solar system as a whole. There is a range of system voltages in solar power systems – 12V, 24V, 48V. Usually, most mobile photovoltaic systems on RV, caravans, campers, or boats have a system voltage of 12V.

For example, let's consider a solar power system of 12V system voltage. A solar panel of a 12V nominal voltage produces a higher voltage (about 18V), to charge a 12V battery bank. A battery voltage of 12V ranges from 10V to 14V, depending on the battery type and battery state of charge. The lowest voltage means a fully

discharged battery, the highest voltage – a fully charged battery. Similarly, a 12V charge controller must provide the corresponding higher voltages allowing the battery bank to get charged.

If you use an inverter, the battery voltage should fall within the inverter's nominal DC input operating voltage window. However, the inverter's output AC ('mains') voltage must coincide with the standard AC voltage, which is 120V for the USA.

So, a 12V solar power system should comprise all these components with their generated voltage falling within these ranges.

**For more info on how solar panels work, you can visit author's here:**

https://solarpanelsvenue.com/what-are-solar-panels-made-of-how-do-solar-panels-work/

**How to orientate in solar panel ratings?**

The power output of a solar panel is rated by its 'peak power,' sometimes denoted in 'watts-peak' (Wp) rather than 'watts (W).' The peak power of the panel is a multiple of its peak current (the current of maximum performance **Imp**) and peak voltage (the voltage of maximum performance **Vmp**).

The peak power of a solar panel is measured in a laboratory environment known as Standard Test Conditions (STC):

- 1,000 watts per square meter falling onto the Earth's surface,
- Temperature 25C (77F), and
- Atmospheric density 1.5.

Although manufacturers state the peak output power of their panels under the STC, these conditions are somewhat idealized and deviate from reality. The main reason for such a deviation is that solar panels typically operate at temperatures higher than 25C (77F), which inevitably reduces the solar-generated power. Eventually in 'real world conditions,' what you get as a peak power from a solar panel is as less as 80-85% of its peak power.

Thus, from a 100W solar panel, you get 80-85W even during the Peak Sun Hours of the day, that is, during the hours of maximum sunlight (which are around noon). What is more, on cloudy days what you get of such a panel would be even far below these 80-85W, for example, 10-20W.

**Connecting solar panels**

Solar panels are connected into solar arrays to increase the total solar-generated power.

Solar panels can be connected in series or parallel. In both connection modes, the total power of the solar array is a sum of the powers of the connected solar panels.

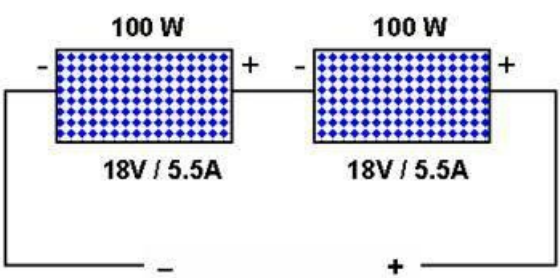
Series connection increases the voltage of the solar array while keeping the same current. In contrast, parallel connection increases the current of the solar array, while keeping the same voltage.

Series connection is preferred both in grid-tied and off-grid residential solar systems because it results in lower currents and hence, reduced cabling costs.

The parallel connection of solar panels is mainly used in mobile solar systems on RV, caravans, campers, or boats. Parallel connection increases the installed solar power while keeping the 12V battery voltage.

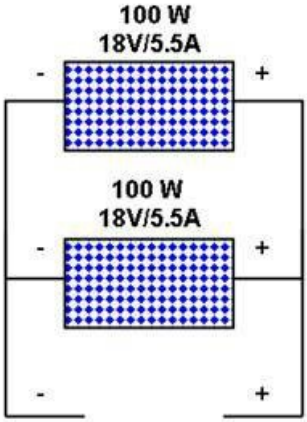
**Example: Series and parallel connection of two 12V/100W (18V x 5.5A) solar panels**

Series connection:




**Total voltage: 2 x 18V = 36V**
**Total current: 5.5A**
**Total power: 36V x 5.5A = 200W = 2 x 100W**

**Parallel connection:**




**Total voltage: 18V**
**Total current: 2 x 5.5A = 11A**
**Total power: 18V x 11A = 200W = 2 x 100W**

Please, have in mind that solar panels produce a voltage higher than the battery voltage. Otherwise, the battery cannot be charged. The typical voltage of a 12V solar panel is about 18V.

**Mixing different solar panels**

Mixing different solar panels can decrease the solar-generated power since the output power is limited by the most poorly performing panel in the array.

Generally, mixing different solar panels is not recommended. By following the below rules, however, you can mitigate the negative impact of such a mixing on the solar panel performance:

- In a series connection, the current passing through the solar panels is limited by the solar panel of the lowest rated current. Thus, if you have a panel of a rated current lower than the current rating of the other panels, the total power of the whole string will go down.
- In a parallel connection, the solar panel with the lowest rated voltage determines the total voltage of the paralleled string. Thus, if you have a panel of a rated voltage lower than the voltage rating of the other panels, the total voltage of the whole string will go down. If you, however, add a new solar panel of a slightly higher rated voltage, only the performance of that new panel is going to degrade.

# Important:

**Avoid mixing different solar panels. If you, however, cannot avoid this, to mitigate the losses:**

- In a series connection, only use new solar panels of rated current equal or slightly higher than the rated current of the other panels.
- In a parallel connection, only use solar panels of rated voltage equal or slightly higher than the rated voltage of the other panels.

**To get more information on this topic, please visit author's site here:**

https://solarpanelsvenue.com/mixing-solar-panels/

**Which solar panels to select for your home solar system?**

Monocrystalline solar panels are the most efficient ones. Their efficiency lies within the range of 12-25% with a typical value of 18%. Polycrystalline panels are similar to monocrystalline ones but they:

- Compared to monocrystalline panels, need a slightly larger area to produce the same amount of electricity,
- Cost less, and
- Are less efficient than monocrystalline solar panels of an efficiency range of 12-25% with a typical value of 15%. However, polycrystalline panels are less expensive than monocrystalline ones and are the most widely used solar panel type today.

# Important:

**Thin-film panels usually need a twice larger area to produce the same amount of electricity, compared to mono- and polycrystalline panels.**

They are the least expensive type of PV panels with the following most common varieties:

- Cadmium Telluride (CdTe) thin-film panels.
- Copper Indium Gallium Selenide (CIGS) thin-film panels.
- Amorphous silicon (a-Si) thin-film panels.

Choosing thin-film panels would mean you have:

- **Minimum** budget, or
- **Quite a large** area to install the PV array.

Thus, unless you have the above combination, it does not seem quite reasonable to select solar panels of efficiency twice less as common.

**For more information on different type of solar panels, you can check on our blog here:**

https://solarpanelsvenue.com/types-of-solar-panels-most-used-pv-solar-panels/

**To get more info about how to choose the best solar panels, you can visit us here:**

https://solarpanelsvenue.com/how-to-choose-the-best-solar-panels/

**Which solar panels to select for your RV?**

The primary purpose of a mobile solar panel system is to charge your leisure battery when there is no shore power nearby. Thus, you might not need any mobile solar system at all, in case you drive your caravan just from an RV park to an RV park with shore power available.

Not all solar panels are created equal; neither are all of them suitable to install on the roof of an RV, camper, or boat.

The best portable solar panel systems for camping are made of monocrystalline cells. The so-called 'rigid monocrystalline panels' are the most durable and have the best warranty.

Cheaper portable solar systems are equipped with polycrystalline cells, but they also come with cheap frames and wiring and lower-grade charge controllers.

Thin-film (amorphous) solar panels are another option for portable solar kits. These panels, however, have a much lower efficiency than crystalline ones and much shorter warranty, because they can be broken easily (they do not have a glass surface) and are cheap to produce. Usually flexible and ultra-flexible thin-film panels are used for roof-mounting where they can match the curves of the caravan's surface. Thin-film panels perform better in hot weather. Their rippled surface, however, allow accumulation of dirt and dust which are not so easy to clean, and reportedly even small water pools that can damage the panel.

Portable solar kits are designed for smaller campers and RVs. They offer you more flexibility in deploying your solar array at a distance from your vehicle that has been parked under the trees. Portable solar kits come with cables, stands, and even mounting tools. Initial costs of portable solar kits, however, are higher, compared to when you build the system on your own.

So, we recommend you to start with monocrystalline panels. If your calculations eventually boil down to a system that is too costly or too big, you could redesign it with polycrystalline panels instead.

**For more info on how to choose the best solar panels for a caravan, camper, RV, or boat, you can visit us here:**

https://solarpanelsvenue.com/types-of-solar-panels-most-used-pv-solar-panels/solar-panels-for-rv/

**The risks of using secondhand or home-made panels**

There are plenty of websites claiming it is possible to launch and run a home solar power system for as less as $200-$300. Moreover, you could find hundreds of websites offering you cheap secondhand panels or solar cells.

**A half-built homemade solar panel, made from individual cells soldered together**



Don't trust such websites! They provide you with wrong or misleading information!

# Important:

**Any credits and rebates you could apply for before the government**

**institutions are NOT valid for home-built solar electric systems and their components!**

What is more, launching a solar power system built of home-made panels could be a violation of local electric regulations. Thus, you might not be allowed even to install them, let alone operating them!

In many countries, it is illegal to export power to the grid by a solar system built of non-approved solar generation equipment.

Building a solar system for around $200 is possible. Such a system, however, is going to be of low power output – around 100 Wp. Indeed, this is not enough to power an entire house.

Rather cheap solar panels, unless they are Chinese-made or home-made, are usually rejected by their manufacturers – either because they are physically damaged or because their characteristics differ from the stated ones. If you use such panels, it might be possible that neither of the stated values can be achieved during operation.

## Important:

**The high price of solar panels is related to the stringent and therefore expensive process of manufacturing.**

Such a manufacturing process requires both expensive equipment to perform some special operations and stringent room conditions (with regards to room temperature, cleanness, pressure).

The manufacturing process is so expensive because solar panels are designed not only to ensure maximum performance upon converting solar energy into electricity but also to withstand harsh weather conditions – cold, rain, snow, ice, and heat.

Using cheap panels to build a solar system is the same as plugging an electrical device you know nothing about into a live electrical network. What you should do is just pray not to see your house on fire!

Sources:

1. Boxwell, Michael. 2012. Solar Electricity Handbook, Greenstream Publishing, Amazon Kindle Edition
2. Pop, Lacho, Dimi Avram (2014-11-26). The Truth About Solar Panels: The Book That Solar Manufacturers, Vendors, Installers And DIY Scammers Don't Want You To Read The Truth About

Solar Panels (Kindle Locations 483-490). Kindle Edition.

**How many solar panels do you need?**

Well, it depends on you want to start with. The number of panels you need depends on how much solar power you have to generate, and this power depends on how much energy you use every day. You can assess this through a load analysis which is the starting point of sizing your solar battery.

A good plan is to start with the maximum possible number of panels that can be mounted on your roof. Another case is to evaluate how many panels you need to provide a regular charge to your battery.

# Important:

**The total daily amount of solar-generated electricity is always related to the Peak Sun Hours (PSH) at your location.** PSH is the number of hours a day during which a solar panel produces its rated voltage. PSH vary depending on the season and location.

**PSH is not the same as available sunny hours.** For example, in January the sun might be up for 7 hours every day, while the PSH might be as less as 2. In the calculations, you can use an averaged value for PSH you can obtain as an average PSH for all the months during which you are likely to need solar-generated power.

All these issues are explained in the section **'Why it is vital to size your system correctly'**. Read on!

**Electricity and solar power basics summarized**

**Power (in W) = Current (in A) x Voltage (in V)**

**Energy (in Wh) = Power (in W) x Time (in h)**

**Battery capacity (in Ah) = Energy (in Wh) / Voltage (in V),**

Where:

W – Watts

A – Amps

V – Volts

h – hours

Wh – Watt hours

Ah – Amp hours

Solar panels are rated in Watts. The solar generated electricity, however, is estimated in Watt-hours, since it's not power but energy.

Electrical devices and appliances (also known as 'loads') are rated in Watts.

Batteries are rated in amp-hours. If you need to recalculate the capacity of a battery in watt-hours, you should multiply the rated amp-hours **C** by the battery voltage **V**:

**E (in Wh) = C (in Ah) x V (in V)**

# Important:

Do not mistake the nominal voltage of a solar panel with the open circuit voltage (**Voc**). **Voc** is always higher.

For a 12V solar panel, the nominal voltage is 12V, while the **Voc** is 17-18V.

For a 24V solar panel, the nominal voltage is 24V, while the **Voc** is 34-36V.

Typically, smaller solar panels are 12V, while larger are 24V. Also, lower-wattage solar panels (below 150 Wp) are usually 12V, while higher wattage panels (above 150 Wp) are usually 24V.

Each solar array can be further upgraded (expanded) with more solar panels. You should, however, consider the consequences of mixing different solar panels.

Parallel connection of solar panels is less tolerant to shade. Parallel connection, however, requires using thicker and larger wire. Such a wire is always harder to work with – it does not bend easily around corners and more laborious to crimp. It is also more expensive than thinner wire.

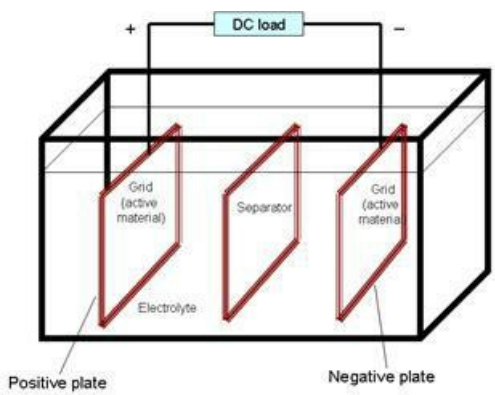
## *Batteries*

### Why does a solar power system need a battery?

When the sun is shining, solar panels are generating electricity but they cannot store it. On the other hand, you use many of your appliances not only in the daytime, but also at night or when it's cloudy. The most popular solution to this problem is to use batteries.

### What are solar batteries and how do they work?

Batteries are electrochemical cells connected in series. An electrochemical cell converts chemical energy into electrical energy, so batteries generate electricity.




As you already know, batteries generate DC power, just like solar panels. Not all batteries, however, are capable of storing solar-generated electricity. Thus, not every battery can be used as a 'solar' one.

Starting (also known as 'cranking') lead-acid batteries are used to start engines, due to their capability of delivering a high amount of power for a short time. They, however, show rather poor performance when used to store solar-generated electricity.

Unlike starting batteries, typical deep-cycle batteries (also known as 'domestic' or 'residential' ones) are capable of delivering a small amount of electricity over a long period.

Also, while starting batteries are immediately recharged after starting by the car alternator, deep-cycle batteries need to be recharged at a much slower rate. A ‘deep cycle’ means providing a fully charged battery to the solar panel system, discharge it down to the recommended 50% (for lead-acid batteries), and then fully recharge it.

Every deep-cycle battery has a rated number of charge/recharge cycles it can withstand before it has to be replaced. A deep-cycle lead-acid battery can withstand between 500 and 1,000 cycles, with a typical value 700-800 ones.

**What kinds of batteries are used in solar power systems?**

There are two main battery types used in solar panel systems today – lead-acid and lithium.

Lead-acid batteries come in a variety of configurations – flooded, gelled, and sealed AGM (Absorbed Glass Mat, also known as 'dry cells'). Although all these are based on the same chemistry, they differ in the construction of their plates.

Flooded lead-acid batteries have removable caps and need regular maintenance. Gelled and AGM batteries are sealed, maintenance-free and are also known as 'valve-regulated lead-acid' (VRLA) batteries.

Starting automotive batteries (also known as SLI, for 'starting, lighting, ignition') are not recommended for solar panel systems. They are excellent for engine starters where very high current is needed within a short period. However, they are not 'deep-cycle' ones, since they are not intended for frequent and deep discharges. If used in an off-grid solar system, where typical discharges are down to 50%, an SLI battery is expected to fail after up to 100 charge/discharge cycles. Such a battery, however, can withstand thousands of cycles when used for providing instant power and not allowed to be discharged by more than 5%.

Here is how you can discover the state of charge by a 12V lead-acid battery by a voltmeter:

- A voltage reading of 12.6-12.65V – the battery is fully charged.
- A voltage reading of 12.2-12.25V – the battery is half-charged.
- A voltage reading below 12V – the battery is discharged.

A voltage of 12V or lower can damage the battery. A lead-acid battery should not be left discharged for more than a week since the sulfation of the electrodes becomes irreversible.

Every battery, even when left unused, is prone to self-discharge. The warmer the weather, the higher the rate of self-discharge.

A well-maintained lead-acid battery can stand up to 5 years and more.

There are two main types of lead-acid batteries – flooded (wet) and sealed.

Flooded batteries have a liquid electrolyte. They need to be vented during

charging and require maintenance in terms of regularly adding distilled water to the cells. Wet lead-acid batteries are widely used in residential solar power systems. They are the least expensive and last 5-7 years if maintained properly. Wet batteries are offered in a wide range of sizes. As their electrolyte can easily be spilled in case of tipping over or fast moving, wet lead-acid batteries are not suitable for mobile solar applications.

Sealed lead-acid batteries do not have a liquid electrolyte. Sealed batteries are gel cell batteries and AGM batteries. Unlike wet batteries, the cells of sealed batteries cannot be accessed, so they do not need maintenance. Although they typically do not require venting, they still have vents to let the hydrogen escape when necessary.

In sealed lead-acid batteries (AGM and gel), the electrolyte is not in a liquid form, so the battery can be placed in any orientation without any hazard of spilling the electrolyte and causing damages. Sealed batteries last shorter than flooded batteries. Gel batteries are more expensive than AGM ones, but they are capable of withstanding low temperatures. Like AGM batteries, they do not require maintenance but are more intolerable to overcharging.

AGM batteries are an excellent choice for mobile solar panel systems since they are:

- Fully maintenance free.
- Safe – there is no hazard of spilling the electrolyte or breaking, or tipping the battery.
- Resistant to mechanical shocks and vibrations.
- Tolerant to freezing – temperatures below 4 degrees C/F or lower.
- Easy to mount and move.

Unlike flooded lead-acid batteries, AGM ones can be stored and operated in a place with poor ventilation. Another benefit is that they can be recharged by a standard automotive battery charger.

A ‘lithium battery’ is quite a common term. For solar panel systems, a ‘lithium’ battery means a ‘lithium-iron-phosphate’ battery. Lithium-ion batteries have a nominal voltage of 3.2V per cell. Lead-acid batteries, whether flooded, gelled or AGM, have a nominal voltage of 2.1V per cell. Thus, 4 lithium cells connected in

series give a total voltage of 12.8V, while 6 lead-acid cells connected in series give a 12.6V.

Apart from a charge controller to monitor the voltage, a lithium battery also needs a battery monitor to track the current. Unlike lead-acid batteries, you cannot estimate the state of charge of a lithium battery only by its voltage.

Although much more expensive (5 times the cost of flooded batteries), lithium batteries have the following benefits:

- Fully maintenance-free.
- Can be stored an operated at any place.
- The most extended lifespan – up to 10,000 cycles.
- Tolerant to overheating.
- The safest – no caustic or poisonous electrolyte and no hazardous gasses vented.
- Can directly replace lead-acid batteries due to the similar charging voltages.
- Do need not to be fully charged before being discharged the next day. Also, lithium batteries do not need to get a full charge regularly.
- Can get fully charged within a much shorter time than lead-acid batteries.
- Can get a full discharge without any adverse consequences.

Lithium batteries need a Battery Management System (BMS) to track whether the individual battery cells do not over-discharge. The BMS ensures the safe operation of a lithium battery by monitoring and protecting the battery cells against overcurrent, overvoltage, or extreme temperatures.

If the voltage of a single cell of a lithium battery drops below 2.5V or rises above 4.2V, the cell will get damaged. The BMS system also balances the charge between the cells if one or more cells are fully charged (and there is a risk of overcharging them), while some other cells are not yet.

**How to prolong the life of your lead-acid solar battery?**

For residential solar power systems, flooded batteries are reported to be the best value for your money provided that you maintain and use them properly. 'Proper maintenance' means regularly charging them, adding distilled water (you should check the water level once per month), and keeping the terminals clean.

Here is in brief what reduces the lifespan of lead-acid solar batteries:

- Deep discharges down to more than 80% of the rated capacity. In contrast, discharging the battery down to as less as 30-40% will significantly prolong its lifespan.
- Regular overcharging causes the water in the electrolyte to evaporate and plates to get corroded.
- Regular undercharging leads to gradual plate sulfation. Thus part of the electrode becomes 'sulfuric' rather than lead, which decreases the available battery capacity.
- Adding anything else but distilled water to the electrolyte results in adverse chemical reactions preventing the normal battery operation.

Here is how you can have a lead-acid solar battery lasting more than 5 years:

- Always buy a new solar battery, never secondhand.
- Always keep the battery fully charged, even when it is not in use. Leaving your battery in a discharged state ('flat battery') quickly results in sulfation which is an irreversible process. When your RV is in the garage, you should disconnect the battery and store it under room temperature.
- Never allow your lead-acid solar battery to drop below 50% state of charge. Every discharge down to more than 80% reduces the capacity and shortens the battery lifespan.
- Do not leave a solar battery on charge for a long time.
- Check the state of charge periodically by a multi-meter. Here is the relation between the battery voltage and state of charge:

| State of Charge | 12 Volt battery | Volts per Cell |
|---|---|---|
| Under charge | 12.9-14.4 | 2.15-2.4 |
| 100% | 12.7 | 2.12 |
| 90% | 12.5 | 2.08 |
| 80% | 12.42 | 2.07 |
| 70% | 12.32 | 2.05 |
| 60% | 12.20 | 2.03 |
| 50% | 12.06 | 2.01 |
| 40% | 11.9 | 1.98 |
| 30% | 11.75 | 1.96 |
| 20% | 11.58 | 1.93 |
| 10% | 11.31 | 1.89 |
| 0 | 10.5 | 1.75 |

- Even low-consumption devices can drain your battery if left connected for a long time
- Faster discharges reduce solar battery capacity. For this reason, you should avoid running many devices simultaneously.
- A battery needs a charger providing charging current which is at least 1/10 of the battery capacity. So, a 100Ah battery should be charged with at least 10 amps charger.
- The self-discharge rate of any lead-acid battery is about 5% per month.
- Regarding solar batteries, you usually get for what you pay. The more expensive a solar battery, the longer its lifespan.

**How many amp-hours of capacity do you need?**

With too much capacity, there is a risk of not fully charging the solar battery, which leads to sulfation. With less capacity than needed, a battery of too small capacity will not be capable of using the full daily Peak Sun Hours (PSH) as it will get fully charged too fast and you might turn out to have invested a lot more in your solar array than needed.

For your RV, caravan, camper, or boat, a leisure battery of how many amp-hours to choose depends on how much electricity you use while camping. After selecting your leisure battery, you have to determine how many watts of solar panels you need to charge the battery. Then you have to select your charge controller and your inverter, should you need AC power. Finally, you should perform the necessary calculations about the wiring, connectors, and fuses.

What is more, with less solar-generated electricity the intended appliances in your household or RV will not be able to receive power for a long enough period.

Here we come to battery sizing. Sizing the battery in a solar panel system is essential. On the one hand, if a solar battery is oversized, it might not be capable of being kept fully charged, which leads to plate sulfation. On the other hand, if a solar battery is undersized, it might not be able to power your devices and appliances long enough.

You can discover more about the batteries in our free definitive guide to solar batteries here:

https://solarpanelsvenue.com/solar-batteries/

## *Charge controllers*

Your solar battery needs to be protected from the solar panels.

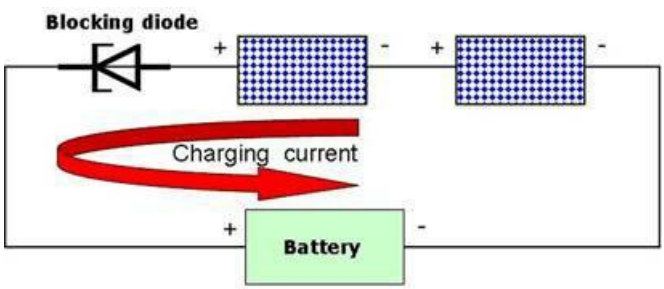
When you connect a battery directly to the solar array, you should consider the following risks:

1. If the solar-generated electricity is not regulated, the battery can get overcharged.
2. At night, when the sun is not shining, the electricity stored can flow back into the solar panels, and the battery can get discharged.

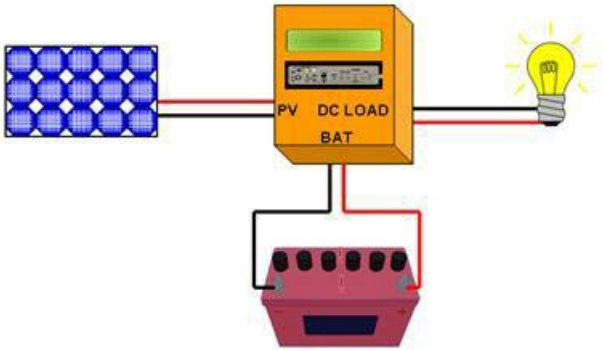
These two conditions can reduce battery lifespan dramatically.

To prevent 1) from happening, you need a charge regulator. It limits the current flowing from the panels to the battery in daytime down to a reasonable level.

The prevent 2) from happening, you need a blocking diode:




A charge controller is a device comprising both a regulator and blocking diodes to protect the battery from overcharging during the day and from discharging at night, and also to match the solar array's voltage to the battery voltage.




More sophisticated charge controllers are also capable of monitoring the battery voltage, thus making it operate at maximum performance.

# Important:

**Do you always need a charge controller?**

If the total installed power of your solar array is less than 1/10 of the battery capacity, you do not need a charge controller. For example, for a battery of 100Ah, you don't need a charge controller if your installed solar power is less than 10Wp. Otherwise, you should install a charge controller to prevent the battery from overcharging and over-discharging.

Here is a summary of the charge controller's main features:

- Preventing the battery from getting overcharged by the solar panels.
- Preventing the current from returning from the battery to the panels.
- Preventing the battery from getting discharged by disconnecting the loads connected to the battery.
- Indicating whether any loads are connected to the battery.
- Indicating whether the solar array is connected.
- Improving battery performance and increasing system efficiency.

To cut a long story short, the charge controller is the battery manager of a solar panel system.

Here are some additional features of charge controllers:

- Indicate the incoming amps,
- Monitor battery temperature to prevent the battery from overheating, and
- Reduce the solar array total voltage down to the battery voltage – 6V, 12V, 24V, or 48V. The latter two are not typical for mobile solar systems.

There are two main types of charge controllers – Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) ones. MPPT controllers perform much better than PWM ones, but they are also more expensive.

PWM charge controllers can be only used with lead-acid batteries. You can never use a PWM controller with a lithium battery as it requires a special battery management system (BMS) and a specific charge profile that cannot be provided by any PWM controller.

PWM controllers are only recommended for small solar power systems. With a PWM charge controller, the voltage of the solar array must be equal to the voltage of the battery bank. On the opposite, MPPT controllers are usually provided with a step-down feature enabling you to connect a 21V or 24V solar panel to a 12V battery.

The primary benefit of MPPT charge controllers is that they are capable of squeezing the maximum solar power from the solar array. This is possible because an MPPT controller operates at the most efficient combination of voltage and current, known as ‘Maximum Power Point’ (MPP). Squeezing the maximum possible solar-generated power means proving the maximum charging current to the battery.

An MPPT charge controller is an excellent solution in colder climates and when you regularly discharge your batteries. MPPT charge controllers are about 2.5 times more expensive than PWM ones.

**Which charge controller is better?**

Selecting the ‘right’ type of charge controller does not mean to decide which charge controller technology is better – PWM or MPPT. It means instead to estimate which type of these would be more suitable for your solar system. The idea is not only to avoid building a system that will not perform well but also save money on buying a costly device that you don’t need.

Above all, however, you should remember never to use a charge controller that is not compatible with your battery type.

**Sizing and installing your charge controller**

If your charge controller is not sized correctly, this can result not only in drastically shortening the battery lifespan but also in damaging both the battery and the controller itself.

The main task when sizing the charge controller is to calculate the solar array's voltage and current and use the calculated values to select the matching model of a controller.

Above all, however, you should determine what type of controller would be optimal for your system. Thus you have neither to pay more than you need nor to buy a controller that can make your system underperform or even damage any of the other components.

When sizing the charge controller, a safety factor of 1.25 should be used. By this factor, the maximum input voltage and maximum input current of the controller are additionally increased by 25%, so that the controller would be able to meet some sporadic increases in voltage and current due to high temperature or light reflection.

The low-voltage disconnect (LVD) feature of the charge controller prevents the battery from over-discharging by disconnecting all the loads connected to it should the battery voltage falls below a certain level. Accordingly, the loads are to be reconnected to the battery when the latter reaches a certain high enough voltage. Most modern inverters and some electrical appliances (e.g., DC fridges) have a built-in LVD feature. If you use DC devices in your RV, your charge controller should be LVD-capable.

Here is how to install your charge controller:

1. Mount the controller.
2. Install the battery wires. Apart from observing the polarity, you should fuse the positive wire.
3. Set the battery type on the charge controller (Flooded lead-acid, AGM, Gelled, Li-Ion).
4. Connect the battery to the battery wires.
5. Connect the solar panel cables to the controller.

6. Connect the solar panels to the cables. If you are not sure about the correct polarity, use a voltmeter.

You can discover more about PWM and MPP|T charge controllers in our free definitive guide to solar charge controllers here:

**https://solarpanelsvenue.com/mppt-and-pwm-charge-controllers-in-off-grid-solar-power-systems/**

## *Inverters*

### Grid-tied solar inverters

Every grid-tied system must have an inverter. A grid-tied inverter converts the DC voltage from the solar array into AC voltage that can be either used right away or exported to the utility grid. As a rule, grid-tied inverters without battery backup are highly efficient and straightforward to install.

A grid-tied inverter only operates when the utility is on. When the utility goes down, the grid-tied inverter turns off immediately.

Most grid-tied inverters are based on Maximum Power Point Tracking (MPPT) – a feature 'squeezing' the maximum possible power from the solar array.

The inverter is connected to the utility grid either directly or via the building's electrical system. In a direct connection, the generated AC electricity is sent towards the utility grid. When the inverter is connected to the utility grid via the building's system, the AC power generated by the PV system is first used by your appliances, and what remains unused, is directed to the utility grid.

A grid-tied inverter must strictly comply with the utility grid's requirements and regulations. For example, grid-tied inverters must generate an AC voltage of a strictly sinusoidal form. One of the main features of a grid-tied inverter is that it stops operating in case of a grid failure. Thus technicians doing any repair works on utility network are prevented from getting an electric shock. This is called 'anti-islanding protection.'

The solar inverter can be either an individual block located outside the solar array or physically integrated into the solar panels.

Since every grid-tied inverter stops working during the grid outage, you do not have any electricity during such an outage as well.

### Off-grid inverters

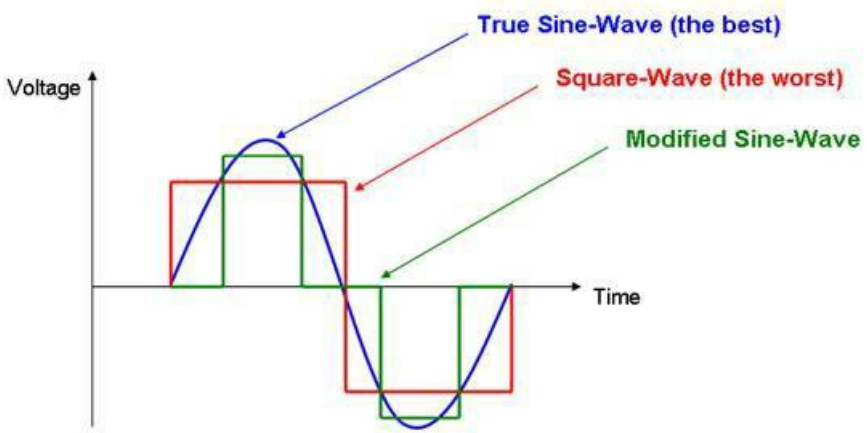
Inverters in off-grid solar power systems differ from grid-tied inverters. An off-grid inverter takes DC power from the battery and converts it to AC power used

by your AC appliances (such as TV, microwave oven, laptop, chargers, etc.).

An off-grid solar system might not contain an inverter if only DC loads are to be powered. Since off-grid systems are disconnected from the utility grid, off-grid inverters do not need to meet the utility grid requirements and regulations.

Grid-tied and off-grid photovoltaic systems use different kinds of inverters. Since inverters for off-grid systems are disconnected from the grid, they do not need anti-islanding protection.

There are three main types of off-grid inverters according to the form of the output AC voltage they produce – True Sine-Wave, Modified Sine-Wave, and Square-Wave ones. Square-wave inverters were the first to appear on the market. They, however, are not a good choice for most of your office and household appliances.




A True Sine-Wave inverter can produce AC voltage identical to the AC voltage supplied to your house outlets by the local electrical company.

A Modified Sine-Wave inverter produces an inferior quality waveform. It's not a clean and stable sinusoid but rather a stair-stepped AC signal. These inverters cost less than True Sine-Wave ones. The problem, however, is that some household appliances (such as TV and audio equipment, digital clocks, computers, and printers, as well as some distinctive brands of small devices like toothbrushes, razors, coffee-makers, etc.) do not operate with Modified Sine-Wave inverters.

Grid-tied inverters are always True Sine-Wave since they must strictly comply with the standard requirements defined for the frequency and waveform.

**Selecting the inverter for your solar power system**

The general rule for inverter selection is that the inverter wattage must be higher than the total watts of the appliances you run together.

If the inverter's output power is less than the total power of the devices you are trying to run, the inverter will turn off.

# Important:

**The inverter's rated wattage is only related to the appliances you are to use and NOT to the solar array's installed power.**

However, the output AC current provided by the inverter at the maximum load, that is, all the appliances you use together, should match the discharging current rate of the battery, recommended by the battery manufacturer. Otherwise, the battery lifespan would be reduced severely.

You can find more information on how these two currents are related and how to select the battery by considering this, in our book:

**Off Grid And Mobile Solar Power For Everyone: Your Smart Solar Guide** [Kindle and Paperback Edition] ASIN: B07B296DGQ

https://www.amazon.com/Grid-Mobile-Solar-Power-Everyone-ebook/dp/B07B296DGQ/

Or, if you are an advanced solar enthusiast, we recommend you:

**The Ultimate Solar Power Design Guide: Less Theory More Practice** [Kindle and Paperback Edition]

http://www.amazon.com/Ultimate-Solar-Power-Design-Guide-ebook/dp/B0102RCNOG/

### *Other solar system components*

Other solar system components, also known as 'Balance of System (BoS) equipment,' include all the mounting and wiring equipment necessary to integrate the solar system into the infrastructure of your house or motorhome. Such additional equipment includes array circuit wiring, fusing, inverter AC and DC disconnects, overcurrent protection and ground-fault protection.

As a rule, fuses, connectors, surge arrestors, and circuit breakers are mounted in one or more junction boxes that are usually located on the periphery of the solar panels and are designed to withstand environmental temperatures and ultraviolet radiation.

**Utility meters** are typical for grid-tied solar systems. Utility metering means selling the excess energy back to the local utility company usually at the same rate you are charged, while you are drawing energy from the utility.

**Battery monitors** are used in off-grid systems. They measure battery capacity and report how much energy is being used. Thus, you get informed whether the battery bank has enough capacity to sustain your needs.

**Fuses** are used to prevent too high currents flowing along other solar strings connected in parallel. The overcurrent protection is used to protect against voltages induced in the solar system internally. Such induced voltages caused by nearby lightning strikes can damage the solar equipment.

**Surge protectors (arrestors)** are used to direct the currents arising upon lightning strikes towards the ground since the photovoltaic array, blocking and bypass diodes, and inverter need protection from high currents and voltages.

**Disconnects** are used for disconnecting the inverter, the loads, and the utility meter from the solar panels. The solar array cannot be switched off – it either produces power in the daytime when the sun is up or generates no power at night. Disconnects can be either DC or AC. A DC disconnect disconnects the link between the solar array and the inverter. AC disconnects are used to separate the household inverter and the loads connected to the solar generator from the utility grid.

**Junction boxes**, also known as '**combiner boxes**,' are used to connect the cables that will further be connected to the inverter, where a solar array comprises a couple of strings. Junction boxes are located on the back of the solar panels and

are typically located on the roof. A combiner box should be provided with double insulation and should allow laying positive and negative cables separately. Often, junction boxes might not be needed at all – for example, if the solar array is built of just a couple of solar panels.

**Cables** are used to connect the individual components of a solar system. Cable is a wire put inside a conduit or a pipe for protection. There is DC cabling and AC cabling. DC cabling comprises the outdoor laid cables, and the wiring between the panels gathered in junction boxes, between the strings gathered in combiner boxes, and the connection to the inverter. AC cabling connects the inverter to the loads and the utility grid.

## *Why it is vital to select the right solar components*

The battery is the heart of your solar panel system. Your solar project should start with evaluating how much energy you need daily. If you are not connected to any utility grid and the sunlight is not sufficient, the battery should provide you with enough electricity, so that you can run your appliances.

Thus, above all, you should start with estimating a battery of what kind and of what size you need. A battery of the wrong type can:

- Cost you too much,
- Have a too short lifespan, or
- Be a hazard for you and your family.

Also, an undersized battery will not be able to cover your electricity needs, while an oversized battery would mean a white elephant at home.

Next, you have to estimate how many solar panels you need to charge your battery. Above all, you have limited space and a limited budget. Your solar array should fit both of these. Next, the solar-generated power has to be enough to charge your battery. So, it's important what kind of solar panels you are going to choose so that the solar array should neither be oversized nor undersized. In all cases, the solar array size should match the battery size.

Also, you need a battery manager, that is, a charge controller. Choosing the wrong type and size of the charge controller will quickly damage the battery whose price can reach up to 60% of the price of the solar system!

Also, to power your AC appliances, you need an inverter. If you select an inverter of the wrong type and size, at best your devices are not going to operate. At worst, they can get damaged.

Finally, as you know, there is additional equipment, such as cables, fuses, and protectors. Selecting and sizing them is vital, as any miscalculation might result in the worst of all – damaging your solar system and setting your house or RV on fire.

In our book, ***'The New Simple And Practical Solar Component Guide'*** [available in Kindle, Paperback and Audio Edition], you can get all the info you need to select the components for your home or mobile solar power system

properly.

You can find it here:
http://www.amazon.com/Simple-Practical-Solar-Component-Guide-ebook/dp/B00TR7IJPU

Also, our books ***'Off Grid And Mobile Solar Power For Everyone: Your Smart Solar Guide'*** [Kindle and Paperback Edition] and ***'The Ultimate Solar Power Design Guide: Less Theory More Practice'*** [Kindle and Paperback Edition] will reveal you how to size the components of your solar power system, residential or mobile, by yourself, fast and easy, thus ensuring both optimal performance and quick return of your investment.

The first book is for beginners to intermediate, while the second is targeted to advanced solar power users.

You can find them here:

**Off Grid And Mobile Solar Power For Everyone: Your Smart Solar Guide [Kindle and Paperback Edition]** ASIN: B07B296DGQ

https://www.amazon.com/Grid-Mobile-Solar-Power-Everyone-ebook/dp/B07B296DGQ/

**The Ultimate Solar Power Design Guide: Less Theory More Practice [Kindle and Paperback Edition]**

http://www.amazon.com/Ultimate-Solar-Power-Design-Guide-ebook/dp/B0102RCNOG/

Also, selecting the solar system components goes hand in hand with system sizing.

A solar power system should be neither oversized nor undersized. An oversized system means a too big system you don't need. An undersized system cannot meet your daily energy needs. Both are a waste of time and money, and that might be the end of your solar project.

Read on to know how solar components are joined together in solar power systems!

# Solar electric systems

There are two basic types of photovoltaic systems:

- Grid-tied
- Off-grid.

The main difference between these two types of PV systems is whether they are connected to the grid or not.

‘The grid’ is the distribution system used by public utility companies to deliver electricity to business and residential consumers. It includes the countrywide network of electrical towers, poles, and wires.

This network delivers electricity from coal burning, nuclear, or water-generated power plants to commercial buildings and residential houses.

## *Grid-tied solar power systems*

Grid-tied (on-grid, grid-direct, grid-connected) photovoltaic systems:

- Produce electricity.
- Use electricity from the grid
- Export solar-generated electricity to the grid.

## Important:

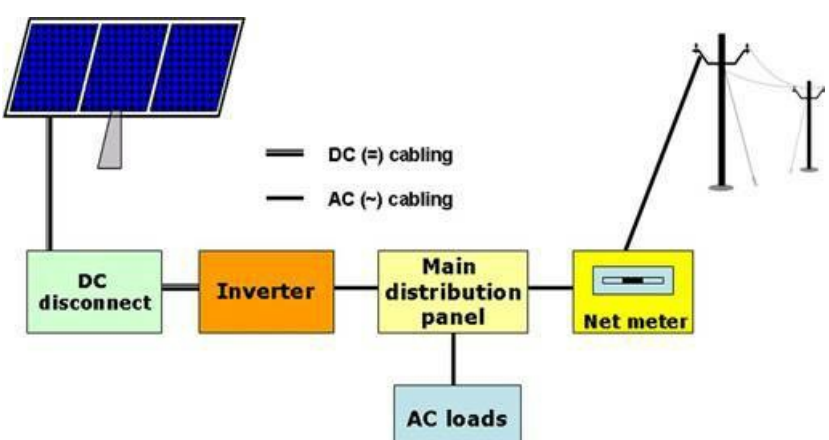
**Grid-tied photovoltaic systems:**

- Can be a source of significant saving from electricity bills.
- Satisfy user's own energy needs.
- Add value to the building.
- Protect the environment.
- Provide energy backup (for grid-tied systems with power backup).

Grid-tied systems can be designed with or without battery backup.

Grid-tied systems without battery backup are built in regions where power outages happen rarely.

Here are the main components of a grid-tied system without battery backup:



**A simplified view of a grid-tied solar system without power backup**

- Photovoltaic array - generates DC electricity from sunlight.
- DC disconnect – disconnects the solar array from the rest of the system.
- Inverter – converts DC electricity into AC electricity.
- Main distribution panel – the connection point between home electrical network and utility grid.
- AC loads – the devices operating on AC electricity.
- Net meter – measures the electricity imported from and exported to the utility grid.

During a power outage, every grid-tied solar system shuts down until the utility is up again. Thus technicians that might be doing certain repair works on the utility infrastructure are prevented from getting an electric shock.

Grid-tied systems with battery backup are preferred in areas where blackouts occur more often. Also, they are installed where power outage is not an option even for short periods – for example, hospitals or communications.

If you have a grid-tied system, you use the solar-generated electricity in the daytime, while the sun is shining. After the sun goes down, your home network automatically switches to using the electricity from the grid. Thus, you have to pay the utility for the electricity provided during night periods only.

You use electricity from the grid when electricity generated by your PV system does not fully cover your household electrical consumption.

Also, if your photovoltaic generator produces more electricity than you consume, the 'excess' of electrical energy is exported to the grid, for which you get paid.

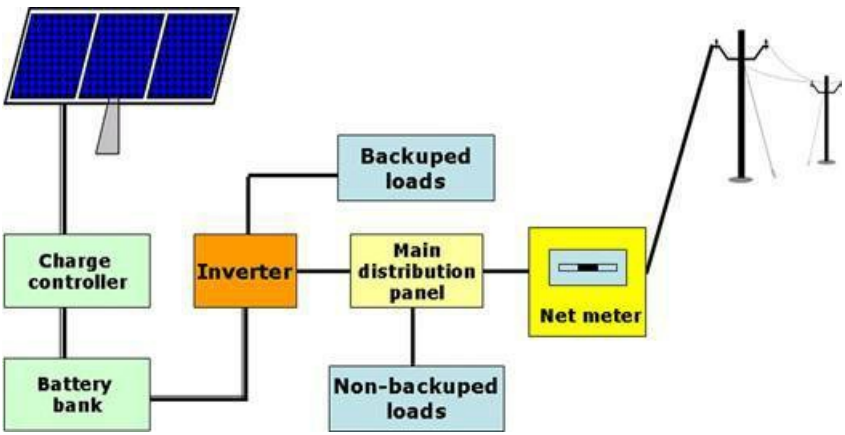
Grid-tied systems are less expensive and require less maintenance than off-grid systems.

A distinct disadvantage is that conventional grid-tied systems (without battery backup) shut down in case of a power outage. A grid-tied system with battery backup can avoid this.

Grid-tied photovoltaic systems with battery backup are similar to conventional grid-tied systems except in their ability to provide power backup for critical loads in the event of a grid power outage.

The solar array generates power while the sun is shining, thus reducing electrical consumption from the grid. If the solar-generated power is not enough to cover the user's needs, the excess electricity is provided by the utility. If the PV system generates more power than needed, the excess solar electricity is exported to the grid.

A grid-tied system with battery backup comprises the following components:




**A simplified view of a grid-tied solar system with power backup**

- Photovoltaic array – generates DC electricity from sunlight.
- Charge controller – regulates battery charging, thus increasing battery lifespan.
- Battery bank – stores the electricity generated by the PV array.
- Inverter – converts DC electricity into AC electricity.
- Main distribution panel – the connection point between home electrical network and utility grid.
- Backup loads – all the AC and DC devices provided with power backup.
- Non-backup loads – those electrical devices which are not provided with power backup.
- Net meter – measures the electricity imported from and exported to the utility grid.

The solar array charges the battery bank via a charge controller. The charge controller regulates the battery charging when the grid fails.

The DC electricity stored in the battery is converted to AC electricity by a battery-based inverter, and then it is delivered to the loads.

Such an inverter:

- Converts DC energy stored in the battery to AC power,
- Manages the battery charge via through an integrated charger, and
- Exports the surplus of energy to the grid thus preventing the battery bank from overcharging when the grid is available.

The inverter in a grid-tied system with battery backup is required by the standard to have 'anti-islanding protection.' Such protection ensures that the inverter is disconnected from the grid during the grid outages, while the solar system is powering only backup loads. During grid outage, backup loads are provided with power supply only until there is enough electricity stored in the battery bank.

## Important:

The apparent advantage of grid-tied systems with battery backup is the ability to provide a backup power supply for critical loads.

The drawback, however, is increased costs for implementation and maintenance, as a result of adding a battery bank and charge controller.

The cost of the battery bank is usually within 20% to 50% of the overall system price. Batteries are to be replaced every 5 years and, for 'wet' lead-acid batteries, the electrolyte should be checked regularly.

**Grid-tied systems summarized**

| | Advantages | Disadvantages |
|---|---|---|
| **Non-renewable fuel generators** | • Low initial expenses<br>• Available on demand<br>• Portable<br>• Very popular | • Relatively costly maintenance<br>• Noise pollution<br>• Air pollution<br>• Low fuel to power conversion efficiency (maximum 25% but upon partial loading often goes below 10%)<br>• A lot of the produced energy is dissipated in form of heat |

**When do you need a grid-tied system?**

## Important:

**A grid-tied photovoltaic system without power backup is a right solution for you…**

**…if you are connected to the grid…**

**…and also if:**

- You want to reduce your monthly electricity bill.
- You wish to add value to your home.
- You want to avoid any future increases in the price of electricity.
- You need to increase your power security.
- You are passionate about renewable energy from photovoltaics.

## Important:

**A grid-tied photovoltaic system with power backup is the right solution for you if:**

- You are a business owner who wants to ensure 24/7 backup and availability of the most critical business processes.
- You want to reduce your monthly electricity bill.
- You wish to add value to your home.
- You want to avoid any future increases in the price of electricity.
- You need to increase your power security.
- You are passionate about renewable energy from photovoltaics.

Sources:

1. Clean Energy Council, Australia. 2002. Grid-Connected PV Systems – System Design Guidelines for Accredited Designers, Issue 3 July 2007, November 2009 Update.
2. Clean Energy Council, Australia. 2008. Electricity from the Sun – Solar PV systems explained, 3rd Edition, June 2008

## *Off-grid solar power systems*

Off-grid systems are not connected to a utility grid. They are preferred where getting connected to a utility infrastructure is too expensive.

Off-grid systems are more expensive than grid-tied systems because they have batteries.

There are two types of off-grid systems – stand-alone and hybrid.

**Stand-alone systems** are purely photovoltaic. They only rely on solar energy to generate power and are not backed by an additional power source.

**Hybrid systems** are modified stand-alone systems provided with an additional power generator operating by wind, combustive fuel, etc.

## Important:

**Here is what to remember above all on stand-alone systems:**

- Having implemented power efficiency is of utmost importance.
- Stand-alone systems cannot provide you with unlimited access to electricity.
- Stand-alone systems can take advantage of DC loads (lighting, refrigeration, electronics).

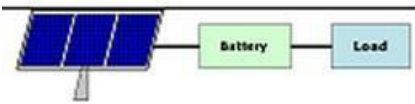
Stand-alone systems are typically supplied with battery storage because electricity is also needed when the sunlight is not enough – in the evening or at night, or during long periods of limited sunlight, such as in winter or on cloudy/rainy days.

If the daily electricity needs are too high, a PV system relying only on solar energy is not suitable. Otherwise, a too large and expensive battery bank is needed, making the purely photovoltaic option far from cost-effective.

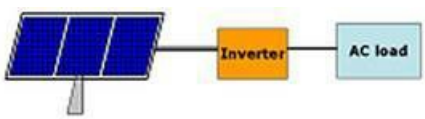
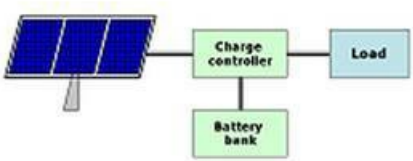
In such a situation, a hybrid off-grid system is a preferred solution. Hybrid systems have an additional power source supplementing the solar battery.

**Directly coupled stand-alone PV systems** are the simplest and the most used ones, as they:

- Only comprise a PV array, a battery (optional) and loads, and
- Are used in wide range of applications.

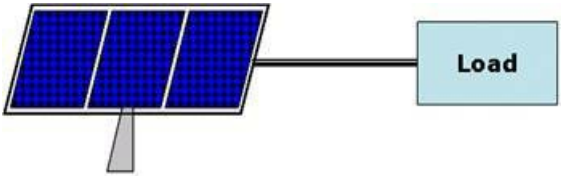
| Directly coupled stand-alone PV system | Applications |
| --- | --- |
|   | Standard DC motors, DC fountain pumps, DC ventilation fans (all of them known as 'day-use appliances') |
|   | Small devices, pocket calculators, watches |

Here are some more configurations of stand-alone systems:

| | |
| --- | --- |
|   | Electricity is only needed while the sun is shining – cooling fans, pumping & irrigation equipment, some small devices (flashlights, clocks, shavers, etc.) |
|   | The system is provided with battery storage, usually combined with a charge controller, so that the electricity produced can be used later. |

In a typical stand-alone system, the solar-generated electricity is used for charging batteries through a charge controller.

A charge controller, however, as well as the battery bank, might not be needed. An inverter might not be needed either. There are stand-alone solar systems where a DC load is connected directly to the solar array – like in pump stations, for example:




If you want your solar array to power AC loads, you need an inverter.

Inverters in stand-alone PV systems are different from inverters in grid-tied systems, although they do the same – convert DC into AC electricity.

## Important:

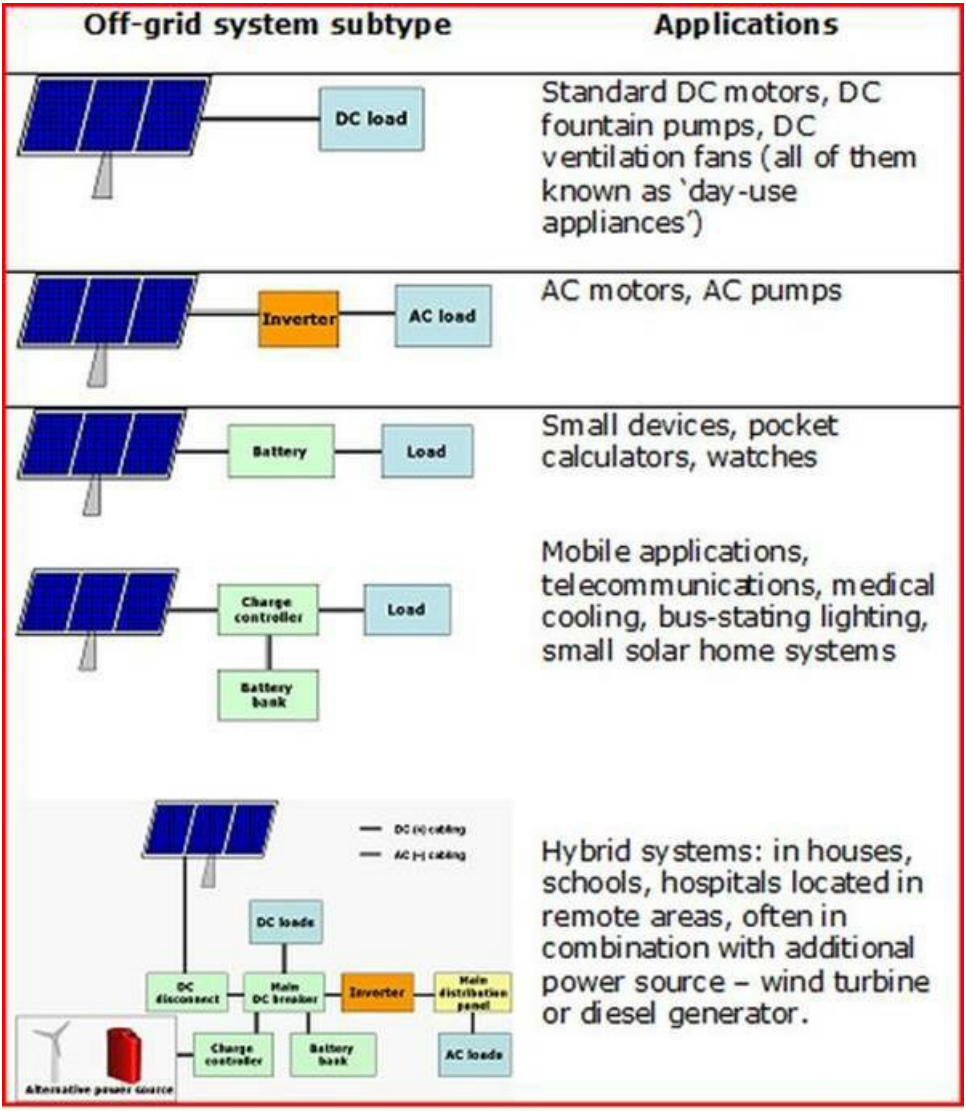
**An off-grid inverter and a grid-tied inverter cannot be used interchangeably!**

In stand-alone systems, it is vital that the solar-generated electricity should be enough to meet the energy needs of all the appliances powered by the PV system.

Stand-alone systems are usually built in rural areas where you have more options for installing solar panels. Usually, solar systems in rural areas are located on the ground rather than on the roof.

Stand-alone systems are supposed to perform well all the year round. In winter the sun is located lower in the sky and nearer the horizon than in summer. So in winter, the solar array orientation should be tilted at a higher angle which is easier to achieve with a solar array mounted on the ground rather than on a roof.

## Off-grid systems summarized




**Off-grid stand-alone photovoltaic systems:**

- Are a reliable source of power.
- Are practically unlimited in size – a stand-alone system could serve a single device or a couple of buildings with a complex electrical network.
- Can be installed almost anywhere in the world.

- Can be less expensive than paying for getting connected to the utility grid, if the utility grid connection point is located miles away.
- Can provide electricity to the most household devices.

**Main applications of off-grid stand-alone PV systems**

- Small solar systems for household use in developing countries.
- Schools and hospitals in developing countries.
- Cooling for medical or veterinary use.
- Solar systems for remote homes or summer villas in well-developed countries.
- Power supply for telecommunication equipment.
- Water pumps.
- Street infrastructure equipment – street lamps, bus station dashboards, parking meters, etc.
- Recreational vehicles.
- Remote meteorological stations and airports.

**Limitations of off-grid stand-alone systems**

- Unless your building is located too far from the utility grid, replacing the utility grid with a stand-alone PV system is not cost-effective.
- Due to solar radiation variability, a PV system does not deliver a maximum performance all the year round. In winter, it is often more cost-effective to buy a hybrid system than spend a fortune on a battery bank and rely solely on solar-generated electricity.
- The solar-generated electricity can be stored in batteries for a limited period only.
- Making your home energy efficient is a must before buying a stand-alone system.
- For stand-alone residential systems, battery banks often need a separate, well-ventilated room, as well as certain maintenance activities.

## Important:

**When do you need an off-grid stand-alone system?**

**An off-grid stand-alone system is the right solution for you if you cannot get connected to the grid…**

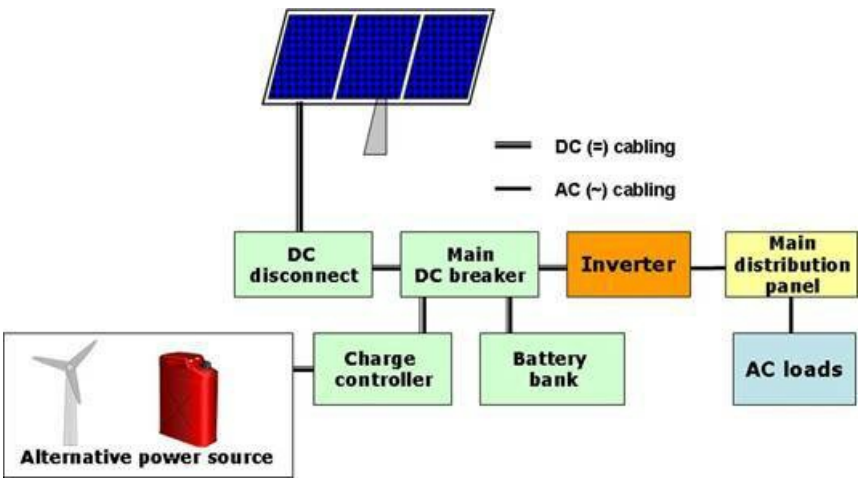
**…and also if:**

- You need electricity 24 hours a day.
- You are passionate about renewable energy from photovoltaics.
- You are not fond of combustible fuel generators based on diesel, propane, petrol, or natural gas.
- You do care about environmental pollution and want to preserve the Earth's fuel resources that are running out.

## *Hybrid systems*

A backup power generator modifies a stand-alone system into a hybrid one.

A hybrid system is a combination of a photovoltaic generator and an alternative power generator – wind or fuel one. Such a generator charges the batteries upon lack of sunlight and is used either as a backup one or when the PV system alone cannot meet the specific energy needs.




**Block picture of a hybrid system**

In a hybrid system, the combustive fuel generator is a source of AC electricity. AC electricity is converted to DC electricity and then is stored in the battery bank.

The batteries are charged both by the PV array and by the generator. The available loads in the building draw power from the batteries.

**Additional power backup sources in hybrid systems**

You can do without a backup generator in a stand-alone system but at a higher cost – you have to oversize your system and choose a battery bank of a higher capacity.

Such a strategy, however, is highly impractical for two reasons:

- The initial costs of batteries are incredibly high.
- Such a system will work with maximum performance just a few months throughout the year (probably in winter), while in the rest of the time it is going to operate far below its maximum efficiency. The value of the electricity produced probably will be not enough to cover the expenses needed for the maintenance support of the battery bank.

The wind and fuel generators on the one hand, and photovoltaic generators, on the other hand, have rather few in common.

This implies the need for additional knowledge of different technologies, each one having its specifics. The minimum overlapping, however, means that the advantages of the other one can easily compensate the drawbacks of the first technology.

A wind generator appears as a suitable supplement to solar generator since in general windy periods very often coincide with periods of sunshine lacking – for example, when it's cloudy or at night.

Also, it is reported that a combination of a solar generator and a wind generator often makes the use of an additional fuel generator redundant.

Fuel generators are the most popular power backup generators. Their main advantages and disadvantages are listed below.

| | Advantages | Disadvantages |
|---|---|---|
| **Non-renewable fuel generators** | • Low initial expenses<br>• Available on demand<br>• Portable<br>• Very popular | • Relatively costly maintenance<br>• Noise pollution<br>• Air pollution<br>• Low fuel to power conversion efficiency (maximum 25% but upon partial loading often goes below 10%)<br>• A lot of the produced energy is dissipated in form of heat |

Fuel generators and wind generators generate AC power. In a stand-alone system, the AC power produced by the fuel generator is used:

- By the existing AC loads, and
- By the battery charger to generate DC power used by the existing DC loads.

## Important:

**PV arrays and fuel generators do not produce the same kind of electricity.**

PV generators are sources of DC power. In a stand-alone solar system, the DC power produced by the PV generator is used:

- By the existing DC loads
- For charging the battery bank.

Upon enough sunlight, the needed AC power is provided by the inverter converting the solar-generated DC power into AC power. If the sunlight is not sufficient, the needed AC power is provided by the fuel generator.

**When compared to wind generators, fuel generators have some benefits:**

- Quite an affordable price.
- Easy to launch.

- Highly portable.
- Operate independently on weather, at any time of the day.

In hybrid systems, fuel generators do not operate continuously but rather during sunless periods only.

So they have:

- More efficient use of fuel.
- A longer lifecycle.
- Lower maintenance costs.

**Benefits of hybrid power systems**

- **A cost-effective solution**, except for the remote spots with difficult access, where maintenance and fuel delivery can be quite expensive.
- **Low initial cost** – fuel generators have affordable prices. There is a great variety of models available at the market.
- **Increased reliability** – there is a simple rule "2 is more than 1", which is applicable if there are two instead of one battery charging sources – a solar array and a generator.
- **Increased efficiency** – a fuel generator is used not only to charge the batteries but also to provide power to the loads operating simultaneously at a given moment. Thus, a generator could be turned on together with a large load consuming lots of power (for example, a dryer and washing machine). If such appliances are not used every day, this might be a preferred way to avoid supplying them with solar-generated power.

**When do you need a hybrid power system?**

# Important:

**A hybrid power system is recommended:**

- If the daily consumption of electricity is more than 2.5 kWh.
- For regions with poor sunlight for long periods.

In these cases, a stand-alone solar system cannot meet your energy needs.

Sources:

1. Clean Energy Council, Australia. 2002. Grid-Connected PV Systems – System Design Guidelines for Accredited Designers, Issue 3 July 2007, November 2009 Update.
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3. Antony, Falk, Christian Durschner, Karl-Heinz Remmers. 2007. Photovoltaics for Professionals: Solar Electric Systems Marketing, Design and Installation, Routledge.
4. Mayfield, Ryan. 2010. Photovoltaic Design and Installation for Dummies, Wiley Publishing Inc.
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Guide (Kindle Locations 1198-1199). Digital Publishing Ltd.

**Which off-grid system to choose?**

## Important:

**Whether to choose a stand-alone or a hybrid off-grid system depends on:**

- Whether you use your building on a yearly or a seasonal basis.
- Whether the site is easily accessible or not.
- How much total daily you need.
- What kind of electrical applications you use – whether critical or not.

In a hybrid system, the alternative generator is usually a diesel, propane or gasoline one, and less commonly – wind generator.

As a rule, hybrid systems are recommended when daily energy needs exceed 2.5 kW.

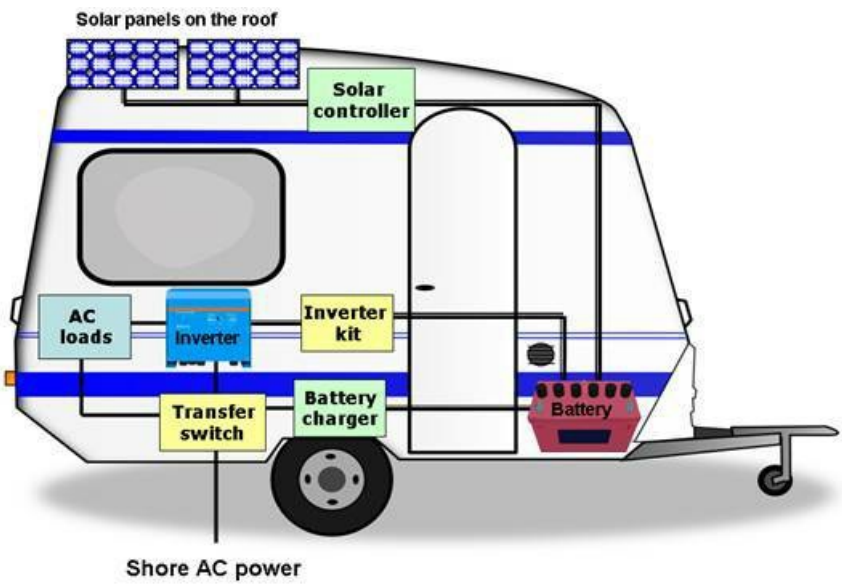
Also, a hybrid system is recommended when the available sunlight in your area is not enough to meet the desired Days of Autonomy (DoA) – the number of days where the battery is not expected to receive a sufficient charge from the solar panels. A higher DoA value always means a more expensive battery bank.

*Mobile solar power systems*

With solar power on your RV, you gain independence from any utility grid – you feel free to park wherever you want, and you don't care about finding shore power.

Mobile solar power systems are known for their lack of maintenance. In a residential photovoltaic system, you usually have a flooded lead-acid battery to maintain. In RVs and motorhomes, batteries are typically maintenance-free – AGM or lithium-ion ones. What is more, solar panels mounted on your caravan are easier to tilt and clean than panels on the roof of your house.

Mobile solar power systems are safe and reliable as long as they are sized and installed correctly. They usually operate at 12 V and up to 40 A.




# Important:

**Here are the most important benefits of using solar panels for camping and boondocking:**

- Solar power is free (although solar power investment is not free).

- Solar power is everywhere you go.
- Solar power enables you to travel to sites with no power hookups available.
- Solar power allows you to save money on conventional power.
- Mobile solar power systems are maintenance-free, excluding the occasional solar panel cleaning. Also, no other activity is required, unless you need to replace your battery after 7-10 years or decide to add more panels to the system.
- Extends the life of your leisure battery.

**Differences between residential and mobile solar systems**

Photovoltaic systems installed on RVs, caravans, campers or boats do not differ much from typical off-grid residential systems regarding the components used – solar panels, charge controller, battery, inverter, cabling, breakers and fuses.

Mobile solar power systems, however, differ substantially from home off-grid photovoltaic system in the following:

- They have much less installed solar power as a result of the limited space of your RV, caravan, camper, or boat.
- The system voltage is most commonly 12V DC.

In residential photovoltaic systems, longer cable runs – between the solar array and the controller or between the battery and the inverter – are quite common. For the sake of reducing voltage drops and avoiding cables of larger gauge, home photovoltaic systems typically are based on a system voltage of 24V, 48V or higher. In RV and marine systems, a system voltage 12V DC is okay since distances are shorter, voltage drops are not so significant, and larger cable sizes are usually not needed. Also, 12 V DC is very convenient as a system voltage for RV and marine solar as many appliances operate directly on 12 V DC.

- Batteries are smaller – in weight, dimensions, and capacity – and typically sealed.

In mobile solar power systems, battery banks are smaller due to the typically lower daily consumption. What is more, flooded lead-acid batteries are rarely used. Instead, the most widely used battery types are sealed lead-acid (typically AGM, rarely gel ones) or lithium phosphate (also known as ‘lithium-ion’ or merely ‘lithium’) ones. In vehicles, wet lead-acid batteries are a safety hazard, while sealed batteries are much easier to handle, transport, and maintain. Sealed batteries can be turned upside down without the risk of spilling the electrolyte and are maintenance-free.

- In an RV solar panel system, it is possible to use high-power devices (such as air-conditioner, heaters, etc.) as long as the RV has been parked and connected to shore power. In residential solar panel systems, high-power loads are generally excluded and replaced with their energy-efficient options.

In an off-grid system, using any high-power appliances with the purpose of air-conditioning or heating is not recommended from an energy efficiency point of view. Using large loads would require a costly battery bank which is expensive, needing a long time to get fully charged and tough to maintain.

- An RV or marine solar panel system typically includes an AC charging system to charge the battery when connected to shore power automatically.

As long as everything with the battery management system is okay, a leisure battery can be charged by several sources at the same time – a solar array, an external generator, and a shore power outlet.

- The solar charge controller can be designed to charge both the leisure battery (which is a deep-cycle one) and the vehicle starting battery.
- Marine solar systems (unlike RV solar ones) should be built with components resistant to the corrosive environment.

Often components for marine and RV solar systems are referred to the same way. Due to the highly corrosive salty air marine environment, marine solar components can be used in RV, while the opposite is often not possible. For this reason, solar components intended for use in marine PV systems are often denoted as ‘marinized.’

Most devices and appliances used in RV or boats run on 12V DC. The size of the battery and the panels depend on how much electricity you need daily, which in turn is up to the appliances you plug in. Often it comes out that you have neither enough room for a battery of specific capacity, nor sufficient space on your roof for the installed solar power you need. In such a case, you have to reduce your power usage.

## *Why it is important to size your solar system correctly*

The size of the solar panel system you need depends on your daily electricity needs, the space available on the roof of your RV or boat, and your budget. Before making up your mind to invest in a mobile solar system, you should be in clear how you are going to use the daily generated solar power.

A wrongly sized photovoltaic system means either spending too much money on equipment you are not going to use fully or building a system that does not cover your daily energy needs and regularly runs out of power. In either of these cases, will have your money wasted and eventually fed up with solar power stuff.

In our books **'Off Grid And Mobile Solar Power For Everyone: Your Smart Solar Guide'** [Kindle and Paperback Edition] ASIN: B07B296DGQ

https://www.amazon.com/Grid-Mobile-Solar-Power-Everyone-ebook/dp/B07B296DGQ/

and

**The Ultimate Solar Power Design Guide: Less Theory More Practice** [Kindle and Paperback Edition]

http://www.amazon.com/Ultimate-Solar-Power-Design-Guide-ebook/dp/B0102RCNOG/

You are going to find all the details you need to build a solar power system matching your specific case. The first book is for beginners to intermediate, while the second is targeted to advanced solar power users.

Also, these books reveal to you how to size an optimal performing solar power system without exceeding your budget available. You'll find out how to expand your system quickly and how to maintain it. Also, you'll be provided with lots of tips and tricks, and you will find out how to avoid all the nasty moments you are likely to experience with an underperforming system, often meaning a loss of money.

Whichever source you decide to choose for sizing your solar system, what you should start with is evaluating your location, also known as 'solar site survey.'

# Solar site survey guide

## *Is your building or motorhome solar-ready?*

Even if your location has excellent solar potential, your building might not be fitted for a photovoltaic system.

**Your building is prepared for installing a solar system if:**

- You have already made it energy-efficient.
- Your roof or yard is unshaded, at least during the sunny hours of the day.
- Your roof has a Southern orientation if you live in the US, UK, Canada, or India, or, a Northern Orientation, if you live in South Africa, Australia or New Zealand.
- Your roof is in excellent condition.

### How to assess your location for the solar resource?

The spot where you intend to install your solar array or park your RV should have:

a. **1.Clear and unobstructed access to the sun throughout the day (between 9 a.m. and 3 p.m.) and throughout the year.**

This means lack of any obstacles between the sunbeams and the solar panel surface – trees, chimneys, lamp-posts, buildings, etc.

b. **2. Preferably a South-facing roof, if you live in the USA, UK, India or Canada, or North-facing roof, if you live in Australia, New Zealand or South Africa**

An orientation towards True South (if you live in USA, UK, India, or Canada) or True North (if you live in Australia, New Zealand, or South Africa) is not mandatory.

A somehow Southeast or Southwest (for the Southern hemisphere Northeast or Northwest, respectively) facing roof is also acceptable.

A deviation within 20-30 degrees of the True South (or True North, respectively) results in a less than 10% degradation of solar array's performance, which is acceptable.

## Important:

**A pure Eastern or pure Western orientation is not recommended** since as a rule, solar panels should be exposed to direct sunlight for at least 6 hours a day.

You should mind that installing a solar system on a roof facing East or West might result in **20% degradation of system performance**, which is a severe compromise!

The roof can be either sloped or flat. Flat roofs allow easier to implement the desired tilt angle of the panels, but a sloped roof will do as well.

c. **3. Enough space for placing the solar panels**

The area you need for your system depends mainly on:

- How much energy it is designed to produce.
- Types of PV panels you are going to install (monocrystalline, polycrystalline or thin-film).
- The size of the panels (to a lesser extent because, as a rule, solar panels do not differ much in size).

## Important:

**The less efficient panels you use, the larger the area you need for your solar array but also, the lower the costs.**

Monocrystalline panels are the most efficient, while thin-film panels are the least efficient ones.

**Why the condition of your roof does matter**

A solar system can be installed on any roof. There are two options for installing the solar panels – either mounting them on the roof or replacing the roof tiles with solar panels.

As a rule, roofs with composition shingles are the easiest to work with, while those with a slate are the most difficult ones.

Here are the drawbacks of solar panels mounted on the roof:

- The panels must be removed upon performing any roof repair or replacement activity.
- Installation of brackets and racks can result in roof leaks.
- Roof warranty can be affected.
- The people to whom you are about to sell your house might find the solar panels of the roof unattractive.

However, the cost of roof-integrated installation is up to 40% more compared to roof-mounted installation.

If your roof is old and is to be replaced soon, to minimize any unnecessary costs, a smart idea is to replace it just while the solar system is being installed.

If you have a new roof, you should consult both your solar vendor and the roof repair company how the installation of a PV system will affect your roof warranty.

Solar panels can be placed on the ground as well, on a fixed or tracking mount.

**Roof-mounted or portable solar panels for your RV?**

When camping or boondocking, you can complement panels mounted on the roof of your RV with a portable solar kit.

Thus you can not only combine the pros of both approaches but also expand the capacity of your solar system by making it ready to meet any increase in your daily electricity needs.

In winter, a solar array mounted on the roof provides much less solar-generated electricity because in winter PSH decreases, and the sun is lower beyond the horizon than in summer. For this reason, it’s more beneficial if in winter you have

a portable (i.e., ground-mounted) solar panel that can be directly tilted towards the sun.

Also, if the installed power of the roof-mounted array is comparable to the capacity of the portable array, you are just free to choose where to set up camp without worrying about how much your system will underperform under shady trees on a bright, sunny day.**Should you tilt the solar panels on your RV?**

Do you know that while a panel pointed directly at the sun is generating the maximum amount (100%) of electricity, such a panel is producing just 10% less electricity when tilted 25 degrees off the optimal angle?

For a mobile solar system, where we talk about just hundreds of watts, tilting and rotating solar panels is not worth the effort. 10% of the solar-generated electricity is not a significant loss.

Tilting the solar panels of your RV only makes sense during winter months when the sun is low over the horizon. In winter, solar panels tilted to 30 rather than 0 degrees results in more than 50% increase in the solar power output. In summer, the effect of tilting can be neglected since tilting would lead to an increase of as less as 10% in the solar-generated electricity. Mind, however, that tilting your panels at an angle for sure makes them more vulnerable to ripping off by the wind.

If mounted on the roof, your panels do not need to be tilted in summer since the sun is high in the sky. In winter, a tilt of 45 degrees towards the horizon is recommended to get the most irradiance from the sun which is low in the sky.

As to the azimuth – if you live in Europe, USA, India, or Canada, your solar array should be oriented towards South, i.e., the position of the sun at solar noon (the moment when half of the time has passed between the sunrise and sunset). If you live in Australia, New Zealand, South Africa, or South America, your solar panels should be oriented towards North.

Also, you don’t need to install an automatic tilting or tracking mechanism for the solar panels on the roof of your RV. The profitability of such a mechanism is questionable, especially in the typical camping season. What is more, it compromises the reliability of your solar array, let alone the additional costs.

## *How to perform a solar site survey?*

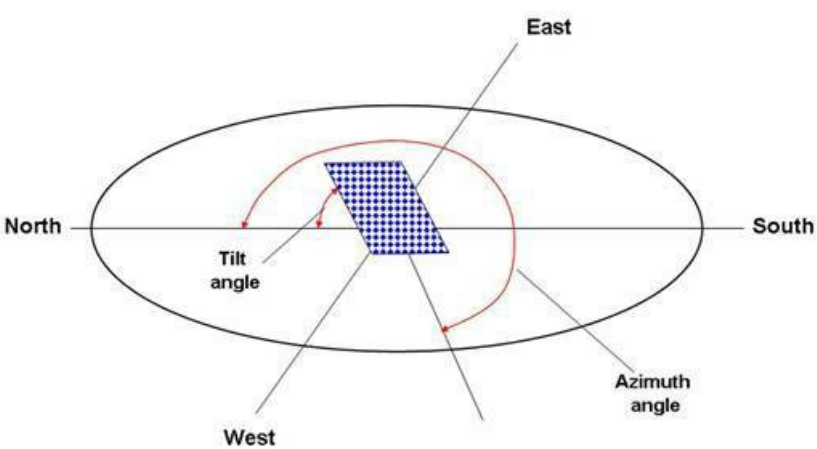
Performing a solar site survey is the starting point of launching every photovoltaic system.

## Important:

**When searching for an appropriate site for your solar panels, you should consider:**

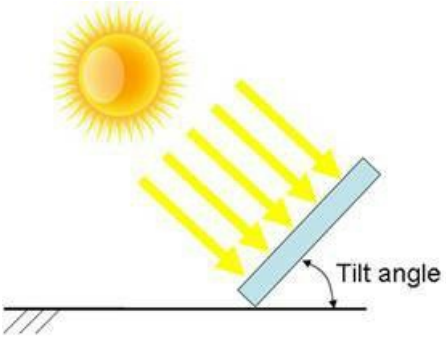
- The orientation towards the sun.
- Lack of any shading obstacles – during the whole day and throughout the whole year.
- Minimization of DC cable length between the solar panels and the charge controller (for off-grid systems) and between the solar panels and the inverter (for grid-tied systems).
- Aesthetics.
- Protection from theft and vandalism.
- Easy access for solar panel installation and maintenance.

To make better use of this guide, you should be familiar with some fundamental issues, such as azimuth and tilt angle:




Azimuth is the angle between the direction perpendicular to the array's surface and the True North.

Tilt (elevation) is the angle measured between a mounted PV panel and a horizontal ground surface:




Solar arrays are recommended to install on roofs facing True South (for North America – USA, Canada, Europe, or India) or True North – if you live in Australia, New Zealand, or South Africa.

Installation of panels on roofs facing North (or South – if you live in the Southern hemisphere) is **NOT** recommended.

*What to do during a solar site survey?*

**Step 1: Assess any possible shading by nearby objects.**

The PV array should be provided with clear and unobstructed access to sunlight between 9 a.m. and 3 p.m. every day, throughout the year.

## Important:

**Shading is not recommended, at least between 9:00 a.m. and 3:00 p.m. Even small shadows can affect the power output of the PV array severely.**

To get the maximum of your survey, you should perform it during a bright and sunny day, preferably in summer, when trees have their full foliage mass.

During the site survey, you should be looking for the following obstacles:

- Buildings. Try to get some info on whether a new building is not being planned nearby, throwing shade to your site.
- Chimneys, power lines, poles, hedges, and neighboring roofs.
- Trees. If you're performing your site survey in winter, you should keep in mind that in summer trees look different than in winter.
- Hills and other earth obstacles – mind that in winter sun is much closer to the horizon than in summer.

A site unshaded during a part of the day might be partially shaded during another part of the day.

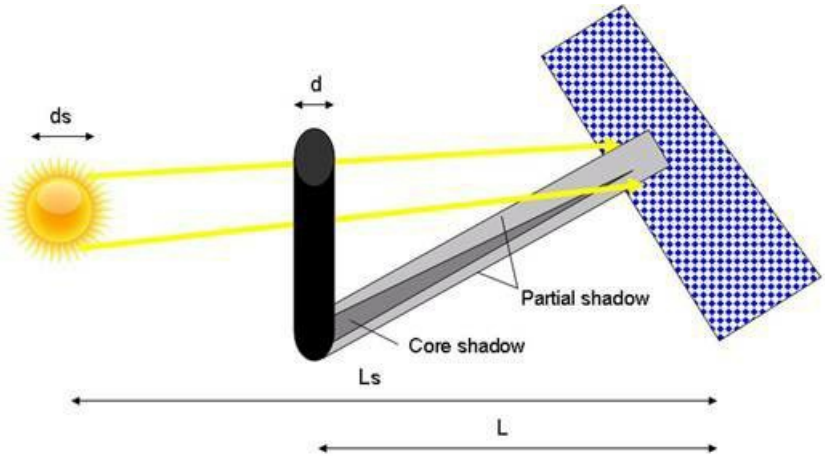
Similarly, if a site is unshaded in summer, it might be shaded in winter, as in winter sun is lower than in summer (and close to the horizon) and casts longer shadows.

## Important:

**Tips on how to avoid shading**

a. **1. Find out the optimum distance between a solar panel and a direct**

**shading object:**




***L = (Ls x d) ÷ ds,***

Where:

***L*** is the optimum distance between a PV panel and a direct shading object, m

***Ls*** is the distance from the Earth to Sun, km

***d*** is the thickness of the shading object, m

***ds*** is the diameter of the Sun, km

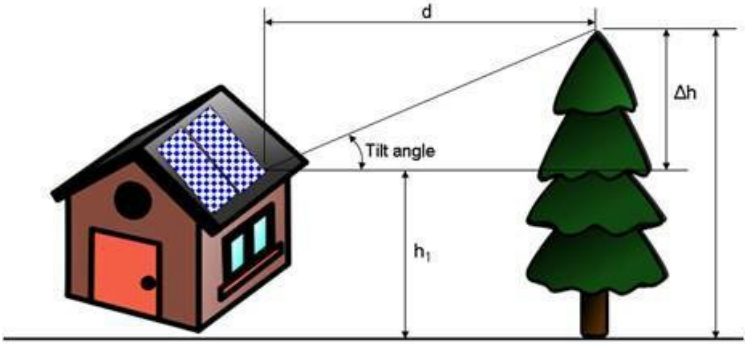
Since the distance from the Earth to the Sun is 150 million km, and the diameter of the Sun is 1.39 million km, the above formula could be simplified as follows:

***L= 108 x d,***

Where ***L*** is in m and ***d*** is in m.

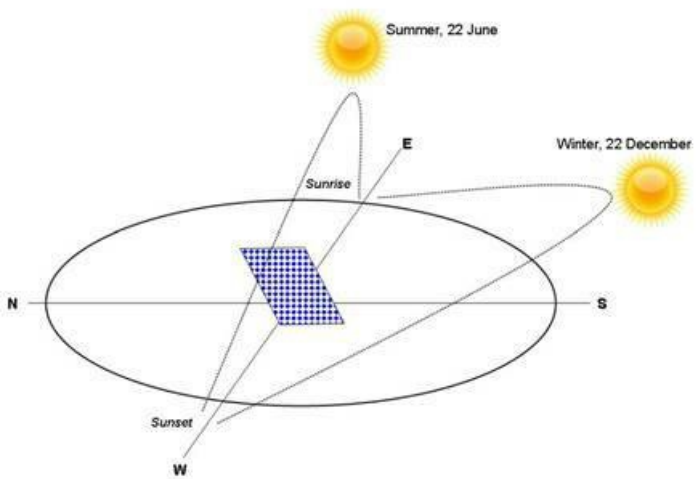
b. **2. Find out the tilt angle to avoid shading of a nearby obstacle**

Here is a practical formula for tilt calculation with regards to a shading obstacle in front of the solar panels.



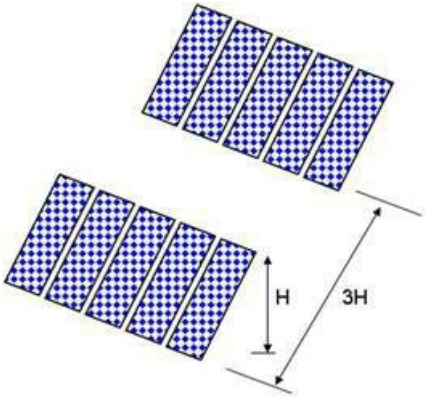

Tilt angle = arctan $[(h_2 - h_1)/d]$ = arctan $(\Delta h/d)$

Regarding any cast-shading objects, it should be noted that in winter months the arc of the sun is the lowest over the horizon.




This means that while an object is not a shading obstacle in summer, it can cast a shadow in winter!

c. **3. Placing the solar panels to avoid inter-row shading**




To avoid inter-row shading, you should place two individual neighbor rows at a space that is at least 3 times the maximum height of a tilted row.

**Step 2: Determine your roof area.**

Usually, access space around the panels adds up to 20% to the solar panel area.

## Important:

**Don't try to use every last square inch on your roof to install a solar array because:**

- The panels get challenging to install.
- The panels get hard to clean.
- Wind loading at the edge of the roof increases.
- From a regulatory point of view, you are likely to violate the provisions for providing available space for fire-fighters and other staff that might need to access the roof area.

**Also, consider the dead spaces around the array. These are the spots that are either shaded or need to be provided between the panels to ensure good cooling.**

**Step 3: Determine the orientation and tilt angle.**

In grid-tied systems, the orientation and tilt angle of the solar panels depend on the roof orientation and slope.

You can use a compass to check what direction your roof faces, and a spirit level to measure the angle of the roof from the horizontal.

If your site is located in the Northern hemisphere, you should look towards the South, East, and West. If your location is in the Southern hemisphere, you should look towards North, East, and West. If you live near the equator, you should look towards East and West.

The ideal roof for mounting your PV array is a roof facing South if you live in the Northern hemisphere and facing North if you live in the Southern hemisphere.

Things, however, are not as crucial as appearing. You can get 90-95% of a PV panel's full power if it is located within 20 degrees of the sun's direction. This means 20 degrees to the East or the West from the full South.

## Important:

**Recommended limits for mounting PV array within:**

Azimuth: ±30 degrees East and West of due South (or due North)

Tilt angle: ±15 degrees from the latitude

**Practical tips to determine the orientation and tilt angle**

## Important:

**A practical rule to find out the optimal orientation:**

At solar noon (when the sun is highest above the horizon) place a straight object, such as a pencil or a ruler, perpendicularly to the surface of your PV panel.

If the panel is perpendicular to the sun, you'll see no shadow. Otherwise, the object will throw a shadow, and you have to make some adjustment to position the PV panel optimally.

## Important:

**Practical advice about determining the tilt angle:**

- For maximizing the solar-generated power in summer, adjust the tilt of the array at the value of the latitude less 15 degrees.
- For maximizing the solar-generated power in winter, the optimal tilt angle is latitude plus 15 degrees.
- For maximizing the solar system performance for the maximum number of hours throughout the year, mount the PV array to a tilt angle equal to the latitude.

## Important:

**What if you select a tilt angle other than the latitude?**

- If your PV array is tilted at an angle ***lower*** than the altitude, your system will produce the maximum power in summer but will underperform in winter. For grid-tied systems, this is not a critical issue – on the one hand, your house is connected to the grid, and on the other hand, there is less sun in winter anyway.
- On the opposite, if the solar array is tilted at an angle ***higher*** than the altitude, your system will produce the maximum power in winter but will underperform in summer.
- Of course, if it is technically feasible, you can choose to set one tilt angle in summer and another one in winter. This is recommended for off-grid systems where the maximum performance is a target throughout the whole year.

## Important:

**Reduce the solar-generated power in summer or winter?**

This depends on the solar system type.

If you have an off-grid (stand-alone) system, it's unlikely that you'd prefer less power output in winter, especially when it's cloudy, and there are less Peak Sun Hours (PSH) than in summer.

With an off-grid system it's normal to struggle for high power output both in summer and in winter to meet most of your daily energy needs.

If you have a grid-tied system, however, we would expect you not bother to seek for high solar performance in winter. First, you are connected to the grid, and your household power needs are satisfied anyway. Second, in winter it's often cloudy, and PSH is less than in summer.

**Step 4: Choose a mounting method of the solar array.**

There are the following types of solar panel mounting:

- Sloped roof mounting
- Flat roof/ground mounting
- Roof-integrated mounting
- Wall mounting.

Flat roof/ground mounting gives you the most freedom to optimize the position of the PV array according to the solar resource. There are four types of flat surface mounted racks:

**Fixed racks:**

- Fixed at one orientation facing due South.
- Slope (tilt angle) equal to the site latitude.

**Manually adjustable racks:**

- Allow changing the tilt angle.
- Usually, the tilt angle is changed at the beginning of every season.
- Result in a 12% power increase compared to fixed mount system.

**Single axis tracking racks:**

- Follow the sun from east to west every day.
- Require additional components and maintenance.
- Increase the power output by 25% compared to the fixed mount system.

**Dual axis tracking racks:**

- Continually orient the PV panels perpendicularly to the brightest part of the sky.
- Require additional components and maintenance.
- More common than single axis tracking racks.
- Increase the power output by more than 30% compared to the fixed mount system.

The other types of mounting give you less freedom since you are not able to orientate the solar array to receive the maximum irradiation. Remember, anyway, that the orientation of the solar panels is more important than the tilt.

## Important:

**Regarding the mounting constructions, mind that:**

- Not every mounting construction is suitable for any panel, while certain kinds of panels are designed for a specific mounting method.
- It's a good plan to ask the supplier of the panels to install them on the roof.
- To ensure sufficient cooling of the panels, you should provide enough room beneath them.
- A design visa or a building permit might be required.
- All the necessary construction regulations must be complied with.

# Photovoltaics in summary

- Solar photovoltaic systems use the sun's light rather than the sun's heat.
- You cannot benefit a solar power system unless you make your house energy-efficient.
- Photovoltaics deliver maximum performance and efficiency at a sufficient amount of direct sunlight, economical use of electricity, and improved energy efficiency.
- Solar irradiation depends on geographic location, roof orientation, slope, and shading.
- The two main types of solar electric systems are grid-tied and off-grid.
- Grid-tied systems are connected to the utility grid. They provide their owners with the opportunity to reduce their monthly electricity bill. Key components of such systems are the solar array and the inverter.
- Off-grid systems are an alternative to the utility grid in rural and remote areas. They are usually more complex and more expensive than grid-tied systems. Off-grid systems can be either stand-alone or hybrid ones. Key components of such systems are the solar array, the battery, and the charge controller.
- Small photovoltaic systems can be more cost-effective than larger solar systems and conventional electrical supply. Larger systems have high initial cost but low maintenance and operational costs.

# Resources on the authors' website

**Free Simple Solar Calculators**

1. -Free Simple Solar Panel Calculator and Solar Power Calculator

Calculate the size of your solar power system, whether off-grid or grid-tied. You will also find instructions on how to calculate the number of solar panels you needed. They are based on calculated values of the size of your system.

http://solarpanelsvenue.com/free-solar-panel-calculator-solar-power-calculator/

2. -Free Simple Solar Cable Calculator

Determine the wire size based on DC power requirements and temperature influence:

http://solarpanelsvenue.com/free-solar-cable-size-calculator/

3. -Free Solar Panel Output Calculator

You can use this calculator to estimate the solar energy a solar panel can produce daily based on the panel's rated power and solar energy available at your place. The results can be used to compare the performance of various solar panels available on the market. The simplicity of this calculator justifies 'the business case' accuracy. For example, you can get more accurate results if you use a calculator considering all electrical parameters of a solar panel and how they depend on temperature.

http://solarpanelsvenue.com/solar-panel-output-calculator/

**Free PWM Charge Controller Calculator**

Use this calculator to size your PWM charge controller based either on solar panels size or to estimate how many panels you can connect to your controller.

http://solarpanelsvenue.com/pwm-solar-charge-controller-calculator/

Stay tuned for more!

We constantly add new free calculators to our site. Check it out regularly.

**Thank you very much for reading this book!**

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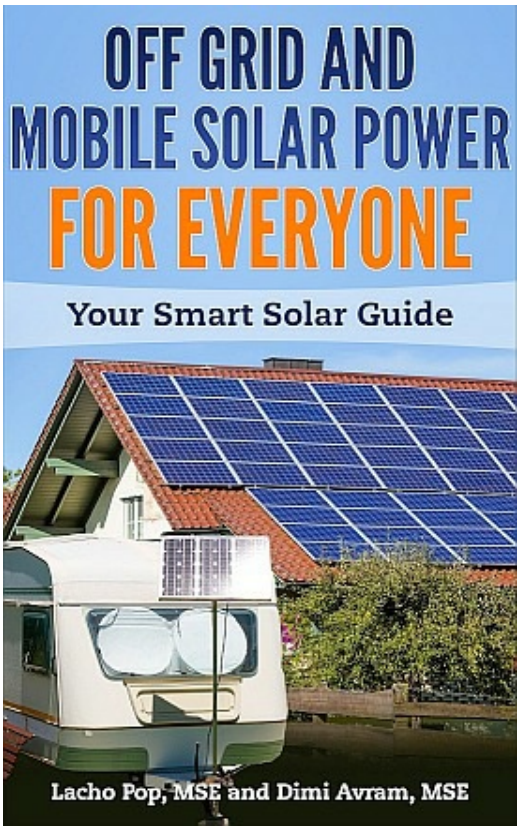


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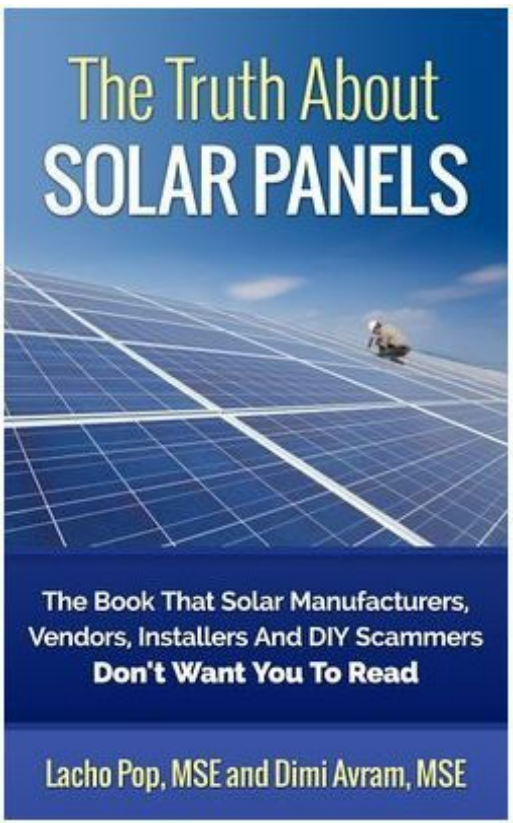


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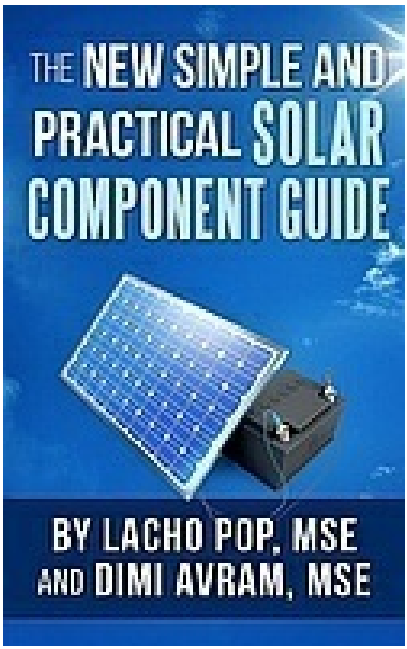


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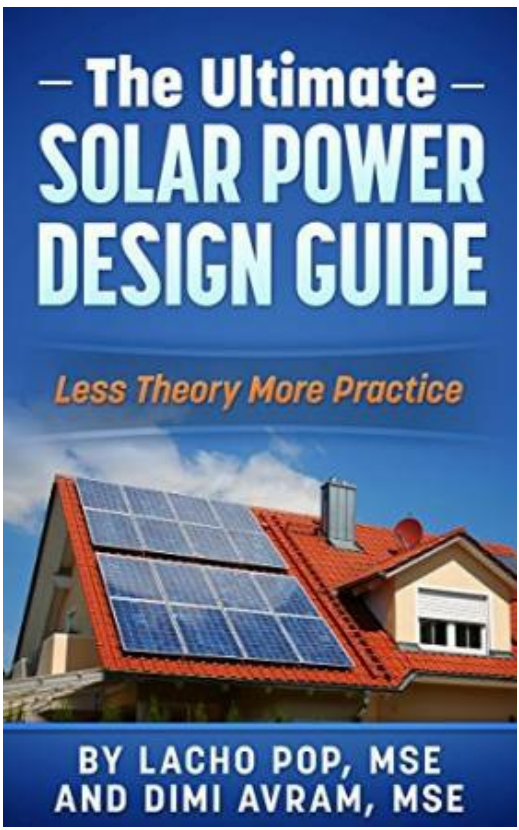


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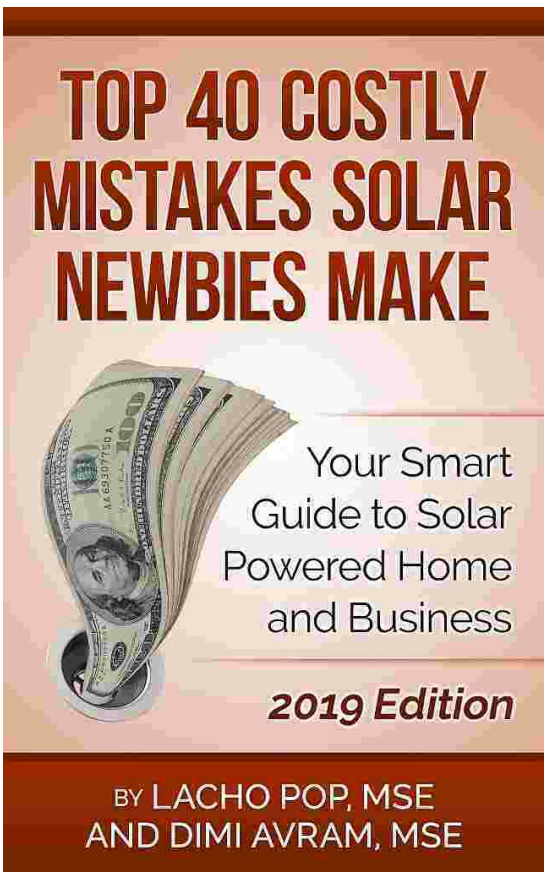


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