Solar Systems

Sunlight and the Photovoltaic Effect

The photovoltaic effect is the process of using sunlight to produce DC electricity in a silent, clean, and autonomous way. The equipment required to produce this electricity is commonly called a “solar panel,” and are modular and require minimum maintenance. Combined with their long durability solar systems are increasing in popularity in remote areas or when an installation is expected to last.

Solar panels are devices able to transform light radiation into electricity through a process of trapping the photons and using them to excite P-type and N-Type semiconductors to move free electrons. Modern photovoltaic panels can generally convert around 15-20% of energy directly into electricity. There are panels that are more efficient, but they are very costly, easy to damage, and are generally not accessible in places where humanitarian organisations might work.

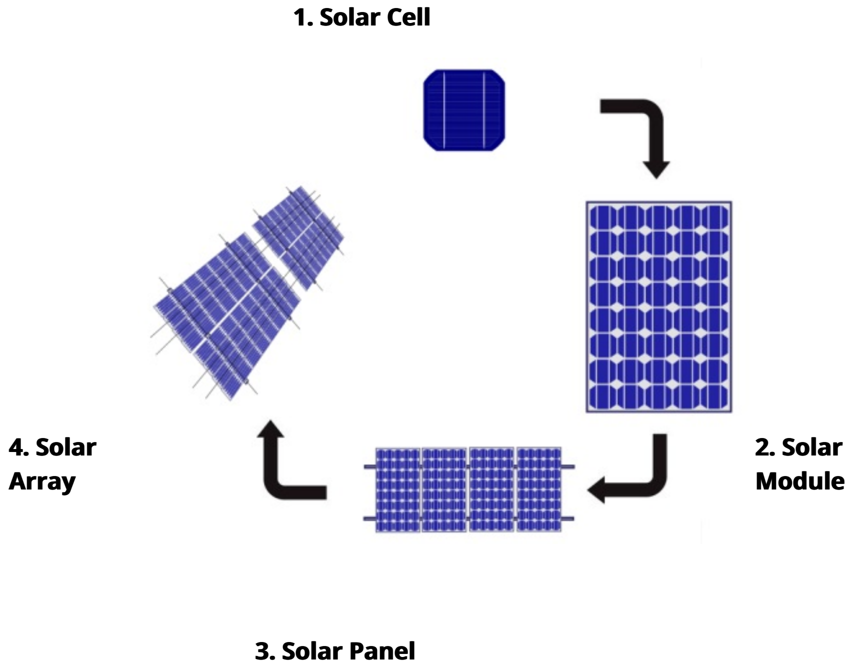
Light enters the device through an anti-reflective coating that minimises the loss of light by reflection. The device then effectively traps the light striking the solar cell by promoting its transmission to the three energy-conversion layers below.

- N-Type Silicon layer; Provides extra electrons (negative).
- P-N junction layer. The absorption layer, which constitutes the core of the device orienting the electrons in one direction.
- P-Type Silicon layer; Creates vacancy of electrons (positive).

Two additional electrical contact layers are needed to carry the electric current out to an external load and back into the cell, thus completing an electric circuit.

Most solar cells are a few square centimetres in area and are protected from the environment by a thin coating of glass or transparent plastic. Because a typical 10cm×10cm (4 inch × 4 inch) solar cell generates only about two Watts of electrical power, cells are usually combined in series to boost the voltage or in parallel to increase the current. A solar, or photovoltaic (PV), module generally consists of 36 or more interconnected cells laminated to glass within an aluminium frame.

One or more of these PV modules may be wired and framed together to form a solar panel, and multiple panels can be combined to form a solar array, together supplying power as a single unit.



A Full PV System Would have...

- Electricity Meter
- AC Isolator
- Fuse Box
- Inverter
- Battery
- Charge Controller
- Cabling
- Mounting
- Tracking System

Solar Cell Degradation

All solar cells - and by extension solar panels - degrade over time. While solar systems draw energy from the sun, the sun also slowly breaks down the components of solar cells. Most commercially available solar panels degrade at an average rate of 2% per year of usage. The duration of use of an installation must be factored for planning and budgeting purposes. For example, a solar array installed in direct sunlight degrading at 2% a year means that after 10 years, the panels will only be roughly 80% as efficient as they were at the time of installation. Less efficiency means less Wattage output from the array, meaning longer periods of of time to charge batteries and less optimal charging times throughout the day. Humanitarian agencies planning to use solar arrays longer than 10 years in a single location may want to consider budgeting for the replacement of panels after 12-15 years if the overall output is no longer meeting the needs of the location.

System Architecture

A complete photovoltaic system may consist of one solar module or many, depending on the power needed. While batteries can be used as back-up of any main power supply, solar systems need a battery system to store the energy produced. Therefore, a solar system always includes some form of battery system, either small or big. These batteries are specifically designed to deliver limited current over long period of time.

A power system can accommodate different electrical loads by regulating the voltage and/or current coming from the solar panels going to the battery to prevent overcharging. Most "12 volt" panels can put out about 16 to 20 volts in optimal conditions, so if there is no regulation the batteries can and will be damaged from overcharging. Most batteries need around 14 to 14.5 volts to become fully charged. Like any other electrical system, proper assessment and cabling are required.

A solar system is usually composed by:

- PV module, solar panel or array, including its multiple types of mounts.
- A battery system.
- A solar regulator.
- Cabling and protections.

Solar systems can accommodate almost any specific need because they are modular in nature. This makes it possible connect PV modules directly do many devices, such as submersible pumps or standalone freezer units, or as a complete solar power arrays able to produce energy for entire offices or compounds.

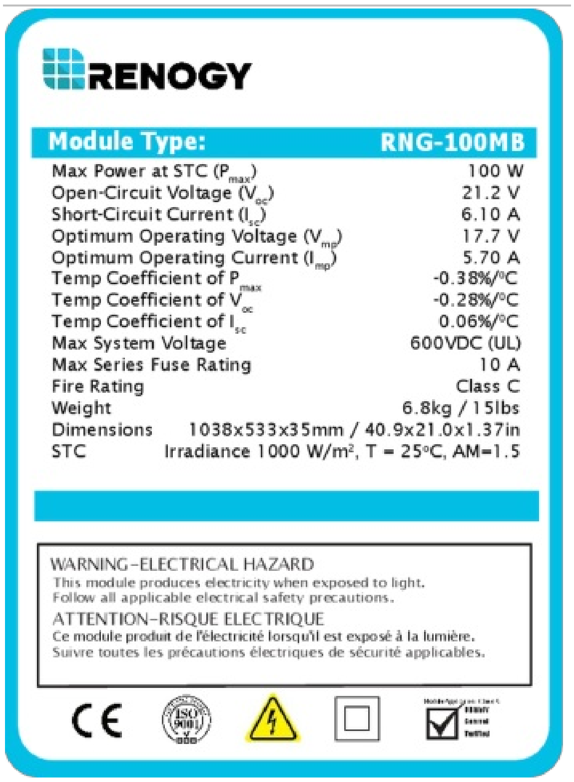
Solar Modules

Solar modules are rated in Watt-peak, represented as nominal peak power (P max), derived from multiplying peak power voltage (Vmp) with its peak power current (Imp):

$$P_{max} = V_{mp} \times I_{mp}$$

A 100Wp solar panel produces 100W under standard test conditions (STC). The STC exist only in laboratories, applying a solar irradiance to panels of 1,000W/m2 with a cell temperature of 25ºC. In a real installation, the actual production of electricity is usually far lower than the peak-power, however the measures remain useful as qualitative reference to compare sizes and capacities as every panel is rated under the same conditions.

Example Label that Comes with Solar Panel

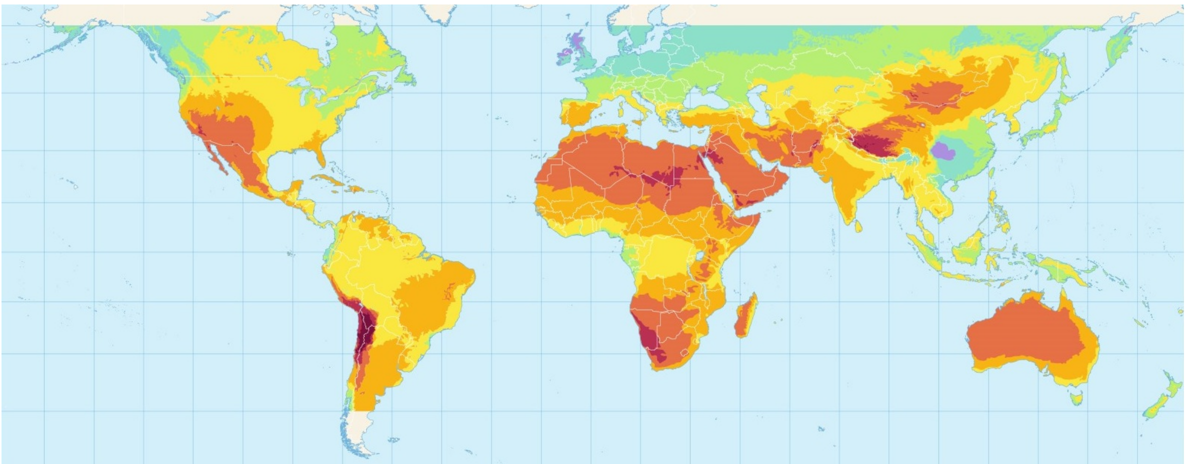


The amount of electrical energy produced during a single by a solar module depends mainly on:

Daily Irradiance: The quantity of energy provided by the sun in one day is the most important parameter. Areas close to the equator have the best average irradiance, however this general rule may vary greatly from one place to the other and from one season to the other. The average performance of a PV system expressed in KwH/m2/day can be referenced in the chart below.

Long Term Average Daily Sum

Long Term Average Yearly Sum



Shade, haze, and cloudy weather: any obstacle blocking sun light will decrease the energy production of the module. In addition, if a solar panel is partially shaded, the electricity production may stop as the shaded cells will consume the energy produced by the rest of the panel. In some cases, a phenomenon called “hot spot heating” occurs when the shaded portions of a single panel rapidly heat up as they consume electricity from an unshaded part, and can rapidly destroy the panel. This can be prevented by using by-pass diodes which are commonly included in PV modules, but it is highly recommended to check on this feature.

Panel orientation: a poorly oriented panel - for example facing the north in the northern hemisphere - will produce far less energy than the panel is rated for, or even no energy at all.

Temperature: Temperature above 25oC also can decrease the amount of energy produced by a solar panel.

Daylight hours: Solar panels produce more electricity when the vertical rays of sunlight are closer together, providing more energy per square cm. By result, solar panels will produce less electricity as the sun is near the horizon than it will when the sun is directly overhead. I practical terms, a solar panel near the equator that is outside for a 12 hour day will only produce the equivalent of 6 hours worth of peak electricity, and this is only under optimal conditions. Changes to the seasons or bad weather will drop this production even further.

As a result of the aforementioned factors, the actual production of electricity from a solar system can be difficult to evaluate. A simple method is to size the installation so that it produces 30% of the daily energy needs during the worst month.

Mounting Panels and Arrays

WPV modules combined to create solar panels, and solar panels combined mounted together to create solar arrays are possible using standard junction boxes - MC3/MC4 type - that are waterproof and easy to connect. Like batteries, panel arrays should only use solar modules with the same characteristics, the same model, and as far a possible the same history.

Mounts

Solar trackers - devices that orient panels towards the sun - are complex, expensive and not recommended outside of industrial uses and/or high latitudes where the sun moves considerably. Some mounts are designed to allow seasonal adjustment, giving the ability to switch manually between two positions during the year, which should be more than enough for most installations.

There are essentially two types of solar mounts available: Ground and Roof mounts. Ground mounted solar panels are easier to install and maintain than roof mounted systems. Roof mounted systems are difficult or impossible to adjust and can cause structural damage due to weight and wind pressure. However, ground mounts have their own problems; they occupy usable space, are more prone shade, and run the risk of accidental damage from cars and people. Mounting decisions should be made depending on the location and infrastructure available.

Battery Systems

Solar batteries are crucial to help keep solar systems running. Without battery storage, electricity will only be available while the solar panels are producing it. Since panels only produce energy during the day while consumption may occur at any time, a stable power bank is essential to store this energy. Please reference the section about batteries for more information.

Solar Regulator

Charger controllers, commonly known as solar regulators are electronic units designed to control the current flow - both the current charging the batteries from the panels, and the current coming from the batteries to offices/compounds.

Solar regulators control the charge and discharge of batteries by disconnecting the panels when batteries are fully charged, and by cutting power to the load when the battery is too low. Another important function of solar regulators is to optimize energy production from the panels by converting the higher voltage output coming from the panels down to the lower input voltage needed by the batteries. The regulator functions as a hub of the installation, and obtaining maximum power output depends on its proper functioning.

There two kinds of solar regulators:

Maximum Power Point Tracking (MPPT):

	The MPPT detects the solar panel output voltage and current in real-time and continuously tracks the maximum power (P=U*I), regulating the output voltage correspondingly so that the system can always charge the battery with the maximum power. This type of power tracking allows for better power production under cloud coverage and variant temperatures. While more expensive upfront, the MPPT Charge Controller will give more power (and potentially reduce the size of the PV module) and extend the lifespan of the batteries connected to it. Certain controllers even allow connection to smart devices for remote control and monitoring.
Battery Charge Method	Multi-Stage MPPT

Maximum Power Point Tracking (MPPT):

Solar to Electric Conversion Rate	99%
Ampere Rate	30A-100A
Scalability/Range	>2KW Large power system
Average Price	120$
Advantages	• Maximum power point tracking algorithm increases power conversion rate up to 99%. • 4 stage charging is better for batteries. • Scalable for large off-grid power system. • Available for solar systems up to 100 Amps. • Available for solar input up to 200V. • Offer flexibility when system growth required. • Equipped with multiple protection devices.
Disadvantages	• High cost, usually twice a PWM. • Larger Size than a PWM regulator.

Pulse Width Modulation (PWM):

	PWM charge controllers can be considered an electric switch between the solar panel and battery packs, programmed to only allow a pre-determined current into the battery. The controller slowly reduces the amount of power going into the battery as the batteries approach maximum capacity. PWM Charge Controllers do not adjust voltage, meaning the batteries and panels must have compatible voltages in order to operate properly. This makes this type of charge controller suitable for smaller solar applications, or for installations that feature lower voltage panels and limited size battery banks. PWMs are a more affordable option but will result in a lower power production from the PV.
Battery Charge Method	3 Stage PWM

Pulse Width Modulation (PWM):

Solar to Electric Conversion Rate	75%-80%
Ampere Rate	20A-60A
Scalability/Range	<2KW Small solar system
Average Price	65$
Advantages	• PWM Regulators have a longer and proven history. • PWM Regulators have simpler structure and are more cost-effective. • Easily deployed.
Disadvantages	• Low conversion rate. • Input voltage must match battery bank voltage. • Less scalability for system growth. • Lower output. • Less protection.

Panel Installation

The storage location of the solar array connected batteries should be identified before sizing and purchasing any equipment. Not only should the space be large enough to mount the required panels, the distance and cable length from the battery storage location will impact the calculated power requirements. Please reference the section on battery installation.

A good location to install a solar array will have the following characteristics:

- Be inside a compound and not visible from the outside. Ground mounted solar panels ideally should be protected by a wall or fence, so sufficient ground space is important.
- Be as close as possible to the battery system.
- Be away from shade, such as trees or buildings.

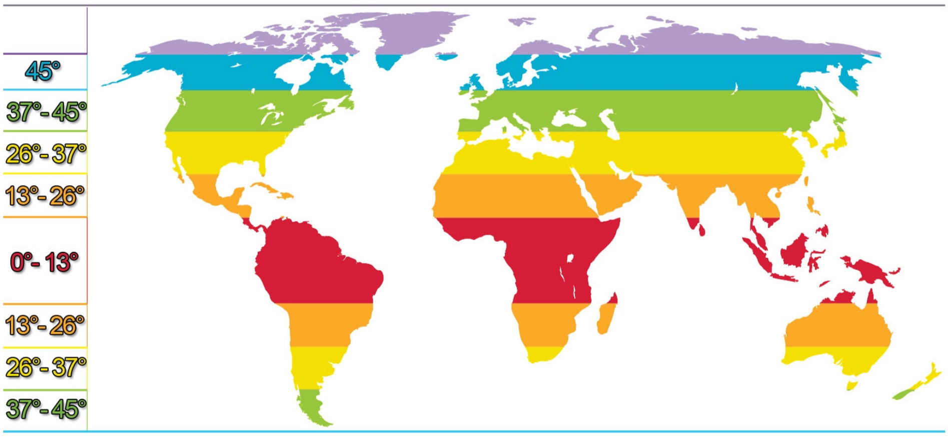
Sometimes it is difficult to completely avoid shaded areas. The priority should be to avoid shade during the sunniest hours of the day (generally 10am to 16pm). Remember that the position and sizes of shadows change with the seasons.

Solar Panel Position

To optimise energy production, solar panels must be carefully oriented to take full advantage of sunlight exposure. Solar panel pointing includes.

- **Orientation** - Orientation is the angle of the solar panel relative to the north-south axis. Solar panels must face the south in the northern hemisphere and the north in the southern hemisphere.

- **Tilt** - Tilt is the angle of the solar panel relative to the horizontal plan. Tilt is more difficult to optimise. Latitude can be used as an approximation of the optimal tilt angle, as referenced in the guide below for panels with fixed angels. However, even on the equator panels should have a minimum tilt angle of 5 to 10° to avoid accumulation of water and dust on the panel.



Connection

The output of the solar panels is connected to the solar regulator, while the output of the solar regulator is connected to the batteries. The solar panel mounting frame is connected to the ground, and a grounding/earthing connection is highly recommended for the regulator and surge protector.

Depending on the power or energy required, panels can follow three different schemes that will give different power and current results. Modules connected in series, parallel, or a combination of both will give different power and energy outputs.

Installation Sizing

PV Modules

Below is a simple method of sizing installations so that they produce 30% of the daily energy needs during the worst months of the year:

Example:

To cover 30% of the energy needs of an installation, how many solar panels will be needed for:

- A planned power need of 12,880Wh
- An annual average daily production is 4.32kWh per 1kWp
- During the worst month, an average daily production of 2.62kWh per 1kWp

The total actual power production needed per day is:

12.88 × 0.3 = 3.87kWh

At an average daily production of 2.62kWh per 1kWp of module, the total daily need is:

3.87 / 2.62 = 1.48kWp

The actual number of solar panels required will depend on the peak-power of each individual panel. Possible configurations might be:

12 x 130Wp panels (1.56kWp)	or	**9 x 180Wp panels** (1.62kWc)	or	**6 x 260Wp panels** (1.56kWc)

As there is an annual average daily production is 4.32kWh per 1kWp, 1.48kWp installation will produce 4.32 x 1.48 = 6.39kWh per day in yearly average, adding to the overall increased energy costs savings.

Regulator

The solar regulator must be sized according to the number and type of solar modules used. Regulator sizing includes:

- The voltage should be the highest possible according to the number of solar modules in the systems.
- Maximum current should be equal to the short-circuit current (ISC) of your solar array. Short circuit current for one individual panel can be found on the identification tag of the panel or in the manufacturer manual. To calculate the short-circuit current of an entire array, combine the short-circuit currents of all panels connected in parallel.

Batteries

Information about Batteries sizing can be found in the section oninstalling a battery system.

Cables and Protection

Information about cable lengths and wire gauges can be found in the chapterelectrical installations.

Safety and Security

Photovoltaic panels produce electricity just like a regular generator. Though the production method may be different, and depending on the size of the array the overall Wattage less than a generator, solar arrays can still produce harmful amounts of electricity.

Handling

Whenever persons must handle a PV solar panels they must wear the properprotective clothing and equipment at all times.

More importantly - PV solar panels produce an electrical current, even when they are not connected to any other device! As long as a panel is partially exposed to light, it will be producing some form of current and can still pose a risk. A panel producing electricity will not make a noise or vibrate, and may not even be warm to the touch. Usually PV solar panels have no form of indicator that they are producing electricity at all. For this reason, PV solar panels tend to look safe to the touch, even when they may not be.

When installing, removing, or simply adjusting solar panels, they should be completely covered. If possible, work can also be done at night time. When carrying or handling solar panels, handlers should note all electrical connector outputs on the side, avoiding making accidental contact with them. Consider all wires coming from a solar panel the same as a live wire coming from a powered grid or live generator.

Security

PV Solar panels should always be in a secure location, just like generators and batteries. The orientation of buildings and vegetation may make this a difficult task, but planners should consider access control.

- If possible, install panels on roofs of buildings, and in areas where persons do not frequently visit - avoid roof top terraces or resting areas.
- Install solar arrays inside of compound spaces, inside the safety of a perimeter wall wherever possible. Even if arrays are inside a compound wall, there should be some form of signage and barrier fencing to prevent visitors or casual labour from accessing the area.
- If solar arrays are installed in the open or in remote locations, then a separate security fence or wall will need to be built around the outside. The equipment is expensive, but it can also harm humans and animals passing by. Persons unfamiliar with solar panels may be drawn close out of curiosity, so signage must be posted in the appropriate local language.