Solar photo voltaic (PV) System

Prepared by:

Ahmed Baqe Salih

Electrical Engineer

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Overview

A photovoltaic system, also called a PV system or solar power system, is an electric power system designed to supply usable solar power by means of photovoltaics. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to convert the output from direct to alternating current, as well as mounting, cabling, and other electrical accessories to set up a working system. Many utility-scale PV systems use tracking systems that follow the sun's daily path across the sky to generate more electricity than fixed-mounted systems.

PV systems convert light directly into electricity and are not to be confused with other solar technologies, such as concentrated solar power or solar thermal, used for heating and cooling. A solar array only encompasses the solar panels, the visible part of the PV system, and does not include all the other hardware, often summarized as the balance of system (BOS). PV systems range from small, rooftop-mounted or building-integrated systems with capacities ranging from a few to several tens of kilowatts to large, utility-scale power stations of hundreds of megawatts. Nowadays, off-grid or stand-alone systems account for a small portion of the market.
Operating silently and without any moving parts or air pollution, PV systems have evolved from niche market applications into a mature technology used for mainstream electricity generation. Due to the growth of photovoltaics, prices for PV systems have rapidly declined since their introduction; however, they vary by market and the size of the system. Nowadays, solar PV modules account for less than half of the system's overall cost, leaving the rest to the remaining BOS components and to soft costs, which include customer acquisition, permitting, inspection and interconnection, installation labor, and financing costs.

A photovoltaic system converts the Sun's radiation, in the form of light, into usable electricity. It comprises the solar array and the balance of system components. PV systems can be categorized by various aspects, such as, grid-connected vs. standalone systems, building-integrated vs. rack-mounted systems, residential vs. utility systems, distributed vs. centralized systems, rooftop vs. ground-mounted systems, tracking vs. fixed-tilt systems, and new constructed vs. retrofitted systems. Other distinctions may include, systems with micro inverters vs. central inverter, systems using crystalline silicon vs. thin-film technology, and systems with module.

Components

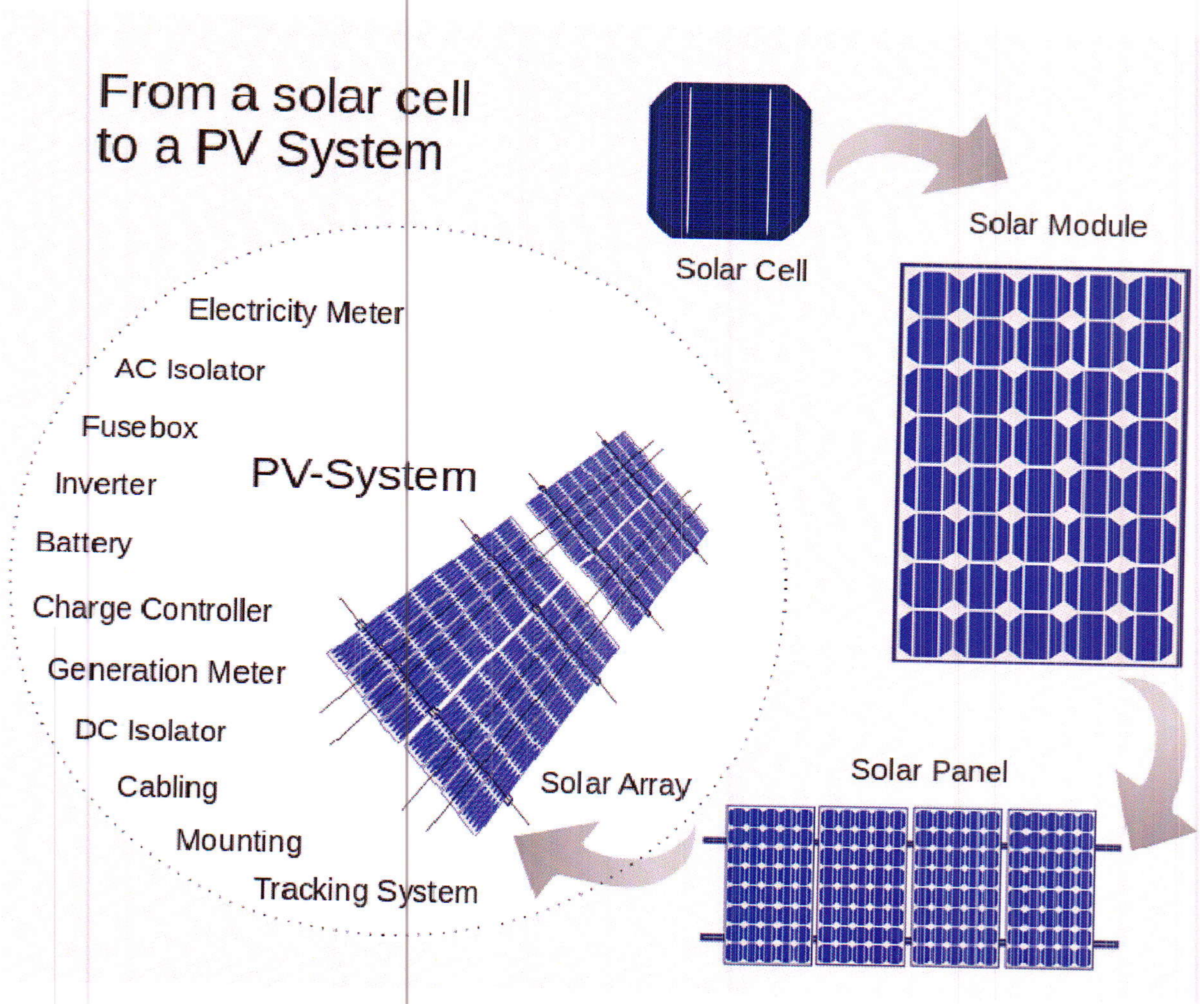


Diagram of the possible components of a photovoltaic system

The components of PV solar system are

- Solar array
- Modules and efficiency
- Shading and dirt
- Insolation and energy
- Mounting
- Cabling
- Tracker
- Inverter
- Battery
- Monitoring and metering

Solar array

The building blocks of a photovoltaic system are solar cells. A solar cell is the electrical device that can directly convert photons energy into electricity. There are three technological generations of solar cells: the first generation (1G) of crystalline silicon cells (c-Si), the second generation (2G) of thin-film cells (such as CDTE, CIGS, Amorphous Silicon, and GaAs), and the third generation (3G) of organic, dye-sensitized, Perovskite and multifunction cells. Conventional c-Si solar cells, normally wired in series, are encapsulated in a solar module to protect them from the weather. The module consists of a tempered glass as cover, a soft and flexible encapsulate, a rear back sheet made of a weathering and fire-resistant material and an aluminum frame around the outer edge. Electrically connected and mounted on a supporting structure, solar modules build a string of modules, often called solar panel. A solar array consists of one or many such panels. A photovoltaic array, or solar array, is a linked collection of solar modules. The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can power lights, motors, and other loads. The modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current. Solar panels are typically measured under STC (standard test conditions) or PTC (PVUSA test conditions), in watts. Typical panel ratings range from less than 100 watts to over 400 watts. The array rating consists of a summation of the panel ratings, in watts, kilowatts, or megawatts.

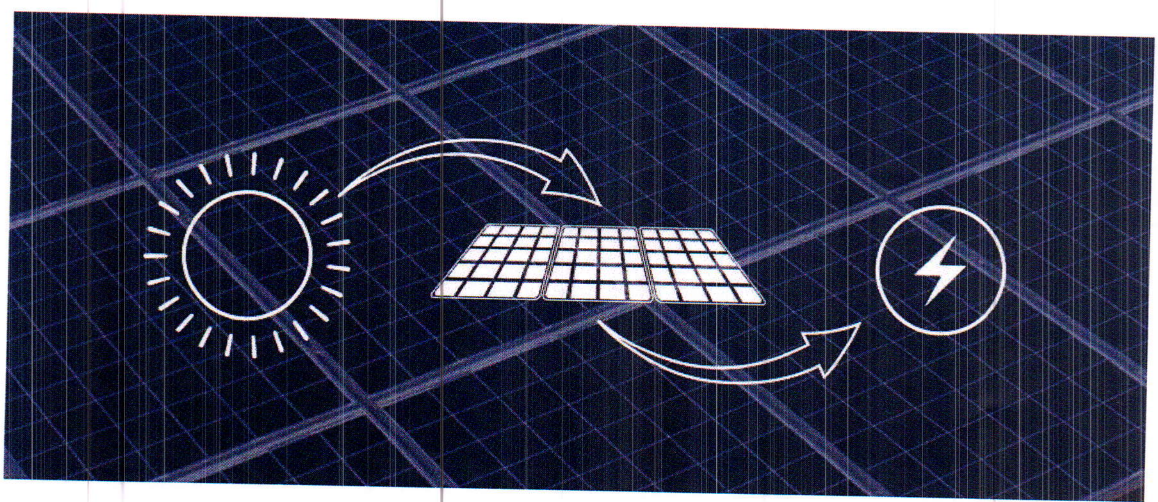
Fixed tilt solar array in of crystalline silicon panels

Modules and efficiency

A typical 150 watt PV module is about a square meter in size. Such a module may be expected to produce 0.75 kilowatt-hour (kWh) every day, on average, after taking into account the weather and the latitude, for an insolation of 5 sun hours/day. Module output degrades faster at increased temperature. Allowing ambient air to flow over, and if possible behind, PV modules reduces this problem. Effective module lives are typically 25 years or more. The payback period for an investment in a PV solar installation varies greatly and is typically less useful than a calculation of investment. While it is typically calculated to be between 10 and 20 years, the financial payback period can be far shorter with incentives.

The temperature effect on photovoltaic modules is usually quantified by means of some coefficients relating the variations of the open-circuit voltage, of the short-circuit current, and of the maximum power to temperature changes. In this paper, comprehensive experimental guidelines to estimate the temperature coefficients

Due to the low voltage of an individual solar cell (typically ca. 0.5V), several cells are wired in series in the manufacture of a "laminate". The laminate is assembled into a protective weatherproof enclosure, thus making a photovoltaic module or solar panel. Modules may then be strung together into a photovoltaic array. In 2012, solar panels available for consumers had an efficiency of up to about 17%,[38] while commercially available panels can go as far as 27%. By concentrating the sunlight, it is possible to achieve higher efficiencies. A group from The Fraunchofer Institute for Solar Energy Systems has created a cell that can reach 44.7% efficiency using the equivalent of "297 suns"

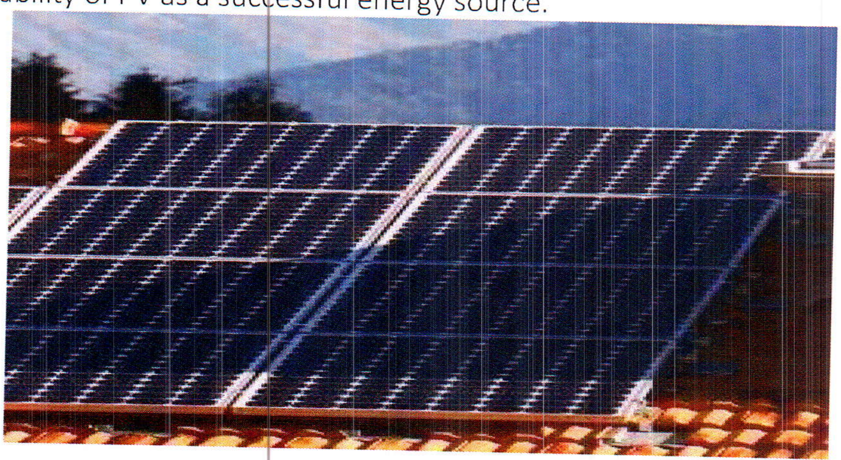


Shading and dirt

Photovoltaic cell electrical output is extremely sensitive to shading (the so-called "Christmas light effect"). When even a small portion of a cell or of a module or array of cells in parallel is shaded, with the remainder in sunlight, the output falls dramatically due to internal 'short-circuiting' (the electrons reversing course through the shaded portion). When connected in series, the current drawn from a string of cells is no greater than the normally small current that can flow through the shaded cell, so the current (and therefore power) developed by the string is limited. If the external load is of low enough impedance, there may be enough voltage available from the other cells in a string to force more current through the shaded cell by breaking down the junction. This breakdown voltage in common cells is between 10 and 30 volts. Instead of adding to the power produced by the panel, the shaded cell absorbs power, turning it into heat. Since the reverse voltage of a shaded cell is much greater than the forward voltage of an illuminated cell, one shaded cell can absorb the power of many other cells in the string, disproportionately affecting panel output. For example, a shaded cell may drop 8 volts, instead of adding 0.5 volts, at a high current level, thereby absorbing the power produced by 16 other cells. It is thus important that a PV installation not be shaded by trees or other obstructions. There are techniques to mitigate the losses with diodes, but these techniques also entail losses.

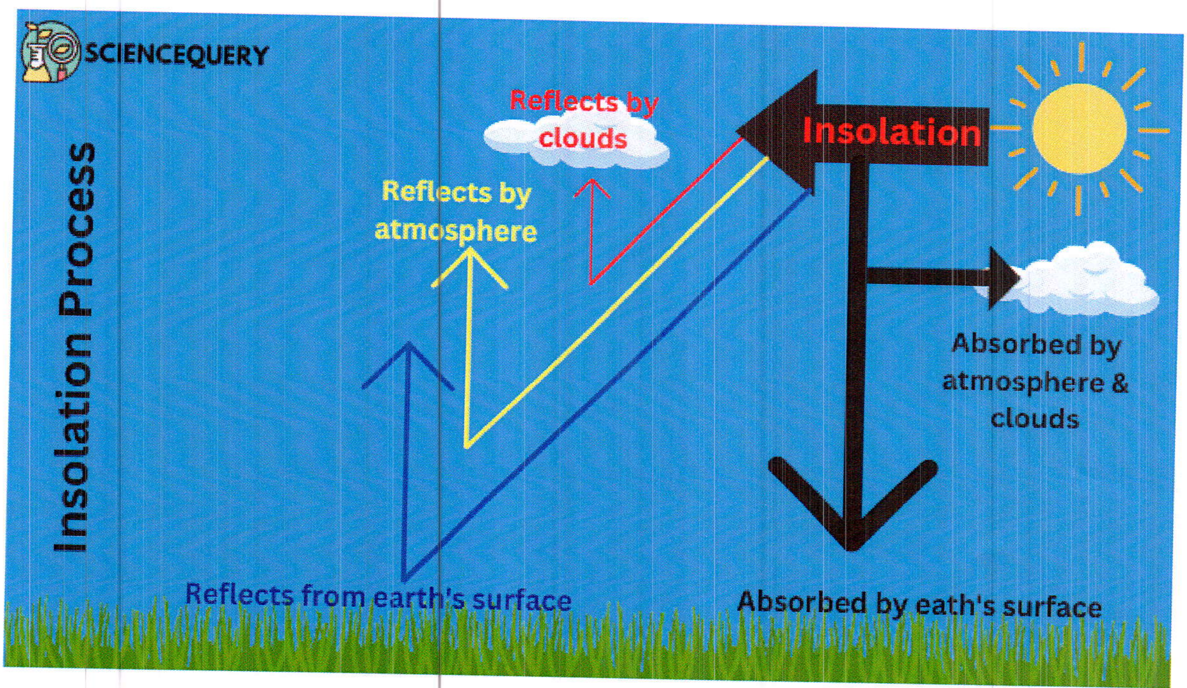
Several methods have been developed to determine losses from trees to PV systems over both large regions using LiDAR, but also at an individual system level using 3D modeling software. Most modules have bypass diodes between each cell or string of cells that minimize the effects of shading and only lose the power that the shaded portion of the array would have supplied, as well as the power dissipated in the diodes. The main job of the bypass diode is to eliminate hot spots that form on cells that can cause further damage to the array, and cause fires.

The long-term reliability of photovoltaic modules is crucial to ensure the technical and economic viability of PV as a successful energy source.



Insolation and energy

Solar insolation is made up of direct, diffuse, and reflected radiation. The absorption factor of a PV cell is defined as the fraction of incident solar irradiance that is absorbed by the cell. When the sun is at the zenith on a cloudless day, the power of the sun is about 1 kW/m2,on the Earth's surface, to a plane that is perpendicular to the sun's rays. As such, PV arrays can track the sun through each day to greatly enhance energy collection. However, tracking devices add cost, and require maintenance, so it is more common for PV arrays to have fixed mounts that tilt the array and face due south in the northern hemisphere or due north in the southern hemisphere. The tilt angle from horizontal can be varied for season, but if fixed, should be set to give optimal array output during the peak electrical demand portion of a typical year for a stand-alone system. This optimal module tilt angle is not necessarily identical to the tilt angle for maximum annual array energy output.



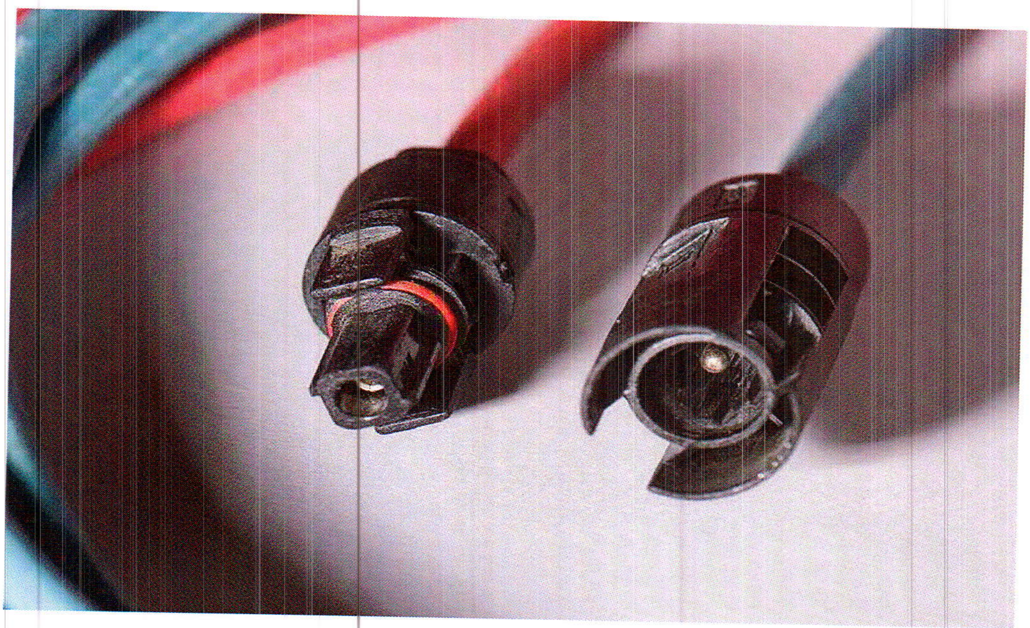
Mounting

Modules are assembled into arrays on some kind of mounting system, which may be classified as ground mount, roof mount or pole mount. For solar parks a large rack is mounted on the ground, and the modules mounted on the rack. For buildings, many different racks have been devised for pitched roofs. For flat roofs, racks, bins and building integrated solutions are used. Solar panel racks mounted on top of poles can be stationary or moving, see Trackers below. Side-of-pole mounts are suitable for situations where a pole has something else mounted at its top, such as a light fixture or an antenna. Pole mounting raises what would otherwise be a ground mounted array above weed shadows and livestock, and may satisfy electrical code requirements regarding inaccessibility of exposed wiring. Pole mounted panels are open to more cooling air on their underside, which increases performance. A multiplicity of pole top racks can be formed into a parking carport or other shade structure. A rack which does not follow the sun from left to right may allow seasonal adjustment up or down

Cabling

Due to their outdoor usage, solar cables are designed to be resistant against UV radiation and extremely high temperature fluctuations and are generally unaffected by the weather. Standards specifying the usage of electrical wiring in PV systems include the IEC 60364 by the International Electro technical Commission, in section 712 "Solar photovoltaic (PV) power supply systems", the British Standard BS 7671, incorporating regulations relating to microgeneration and photovoltaic systems, and the US UL4703 standard, in subject 4703 "Photovoltaic Wire

A solar cable is the interconnection cable used in photovoltaic power generation. Solar cables interconnect solar panels and other electrical components of a photovoltaic system. Solar cables are designed to be UV resistant and weather resistant. They can be used within a large temperature range.



Weatherproof connectors on a solar panel cable

Tracker

A solar tracking system tilts a solar panel throughout the day. Depending on the type of tracking system, the panel is either aimed directly at the Sun or the brightest area of a partly clouded sky. Trackers greatly enhance early morning and late afternoon performance, increasing the total amount of power produced by a system by about 20–25% for a single axis tracker and about 30% or more for a dual axis tracker, depending on latitude. Trackers are effective in regions that receive a large portion of sunlight directly. In diffuse light (i.e. under cloud or fog), tracking has little or no value. Because most concentrated photovoltaics systems are very sensitive to the sunlight's angle, tracking systems allow them to produce useful power for more than a brief period each day. Tracking systems improve performance for two main reasons. First, when a solar panel is perpendicular to the sunlight, it receives more light on its surface than if it were angled. Second, direct light is used more efficiently than angled light. Special anti-reflective coatings can improve solar panel efficiency for direct and angled light, somewhat reducing the benefit of tracking .

Dual axis solar trackers

Inverter

Systems designed to deliver alternating current (AC), such as grid-connected applications need an inverter to convert the direct current (DC) from the solar modules to AC. Grid connected inverters must supply AC electricity in sinusoidal form, synchronized to the grid frequency, limit feed in voltage to no higher than the grid voltage and disconnect from the grid if the grid voltage is turned off. Islanding inverters need only produce regulated voltages and frequencies in a sinusoidal wave shape as no synchronization or co-ordination with grid supplies is required.

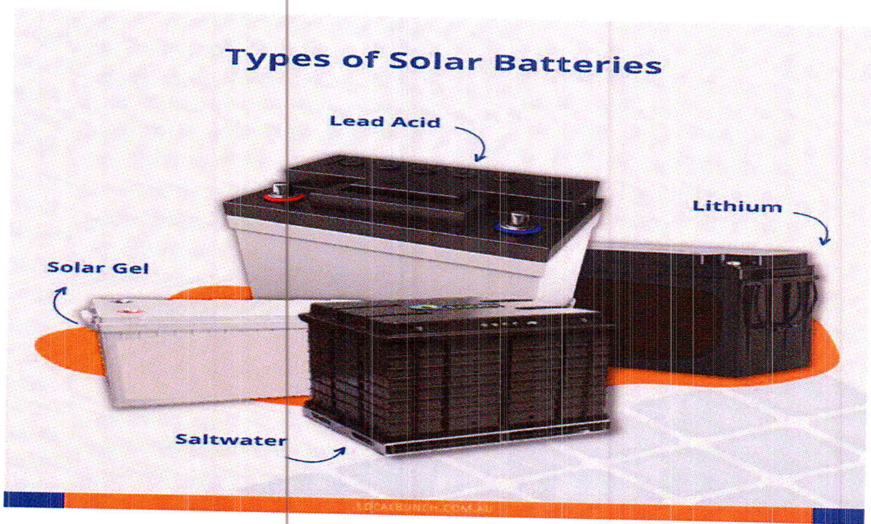
A solar inverter may connect to a string of solar panels. In some installations a solar micro-inverter is connected at each solar panel. For safety reasons a circuit breaker is provided both on the AC and DC side to enable maintenance. AC output may be connected through an electricity meter into the public grid. The number of modules in the system determines the total DC watts capable of being generated by the solar array; however, the inverter ultimately governs the amount of AC watts that can be distributed for consumption. For example, a PV system comprising 11 kilowatts DC (kW DC) worth of PV modules.

STRING INVERTERS

Battery

Common battery technologies used in today's PV systems include the valve regulated lead-acid battery – a modified version of the conventional lead–acid battery – nickel–cadmium and lithium-ion batteries. Compared to the other types, lead-acid batteries have a shorter lifetime and lower energy density. However, due to their high reliability, low self-discharge as well as low investment and maintenance costs, they are currently (as of 2014) the predominant technology used in small-scale, residential PV systems, as lithium-ion batteries are still being developed and about 3.5 times as expensive as lead-acid batteries. Furthermore, as storage devices for PV systems are stationary, the lower energy and power density and therefore higher weight of lead-acid batteries are not as critical as, for example, in electric transportation , Other rechargeable batteries considered for distributed PV systems include sodium–sulfur and vanadium redox batteries, two prominent types of a molten salt and a flow battery, respectively. In 2015, Tesla Motors launched the Power wall, a rechargeable lithium-ion battery with the aim to revolutionize energy consumption.

PV systems with an integrated battery solution also need a charge controller, as the varying voltage and current from the solar array requires constant adjustment to prevent damage from overcharging. Basic charge controllers may simply turn the PV panels on and off, or may meter out pulses of energy as needed, a strategy called PWM or pulse-width modulation. More advanced charge controllers will incorporate MPPT logic into their battery charging algorithms. Charge controllers may also divert energy to some purpose other than battery charging. Rather than simply shut off the free PV energy when not needed, a user may choose to heat air or water once the battery is full.



Monitoring and metering

- The metering must be able to accumulate energy units in both directions, or two meters must be used. Many meters accumulate bidirectional, some systems use two meters, but a unidirectional meter (with detent) will not accumulate energy from any resultant feed into the grid. In some countries, for installations over 30 kWp a frequency and a voltage monitor with disconnection of all phases is required. This is done where more solar power is being generated than can be accommodated by the utility, and the excess cannot either be exported or stored. Grid operators historically have needed to provide transmission lines and generation capacity. Now they need to also provide storage. This is normally hydro-storage, but other means of storage are used. Initially storage was used so that baseload generators could operate at full output. With variable renewable energy, storage is needed to allow power generation whenever it is available, and consumption n whenever needed.

Solar Energy Monitor DC Power Meter for Battery System

How to do solar panel calculation:

To make the most use of solar panels, here are some calculations to consider before you invest in them:

1. Solar panel Size.

To calculate the solar panel size for your home, start by determining your average daily energy consumption in kilowatt-hours (kWh) based on your electricity bills. Then calculate your daily energy production requirement by dividing your average daily energy consumption by the system efficiency

Next, consider the amount of sunlight available in your location, as areas with more sunlight require fewer panels. Determine the solar panel capacity by dividing the daily energy production requirement by the average daily sunlight hours.

Account for panel derating to factor in efficiency losses. Divide the actual solar panel capacity by the capacity of a single panel to determine the number of panels needed.

For example, if your average daily energy consumption is 30 kWh and the system efficiency is 80%, and you have an average of 5 hours of sunlight per day, you would calculate your daily energy production requirement as follows.

Daily Energy Production Requirement = 30 kWh / 0.8 = 37.5 kWh

Assuming a derating factor of 85%, the solar panel capacity needed would be:

Solar Panel Capacity = 37.5 kWh / 5 hours = 7.5 kW

Considering the derating factor, the actual solar panel capacity would be:

Actual Solar Panel Capacity = 7.5 kW / 0.85 = 8.82 kW

If the capacity of a single solar panel is 300 W, the number of panels required would be:

Number of Panels = 8.82 kW / 0.3 kW = 29.4 panels

It's important to consult a professional installer to validate these calculations and assess your specific requirements

2. Solar panel Output

Before installing solar panels, it is also crucial to calculate their output to ensure optimal performance. Usually, solar panels generate energy ranging from 250 watts to 400 watts per hour. But their actual output is influenced by a variety of variables, such as their efficiency, orientation, and location. Suppose there is an energy loss of 25%, then you can get the formula:

Daily watt hours = Average hours of sunlight × solar panel watts × 75%

The following is an example

If you reside in an area that receives 5 hours of maximum sunlight and your solar panel has a rating of 200 watts, the output of your solar panel can be calculated as follows

Daily watt hours = 5 × 200 × 0.75 = 750W

That means a solar panel that has a capacity of 200 watts can produce approximately 750 watt-hours

3. Solar panel efficiency

The efficiency of a solar panel refers to the amount of sunlight that is converted into usable energy. Panels with higher efficiency are able to generate more power from the same amount of sunlight. Therefore, it's vital to consider the solar panel efficiency. Below is the formula to calculate it

Efficiency (%) = [(Pmax ÷ Area) ÷ 1000] × 100%

In this formula, the Pmax stands for the maximum solar panel power; the Area equals the width times the length of solar panels; 1000 is the conversion factor that transforms power output per unit area from watts per square meter to percent.

For instance, assuming a solar panel has a surface area of 1.6 square meters and the highest power output of 200W, then its efficiency would be

Efficiency = [(200 ÷ 1.6) ÷ 1000] × 100% = 12.5%

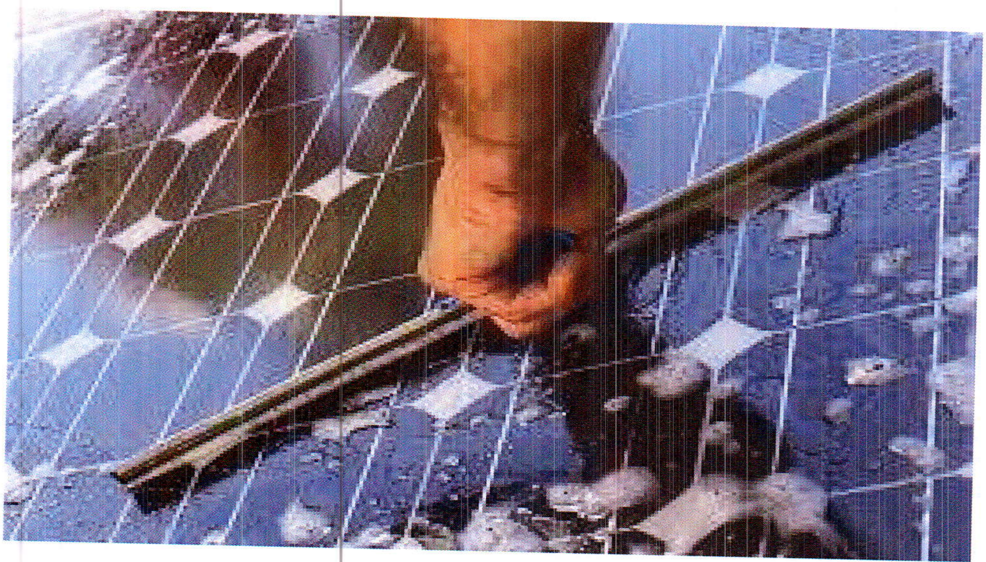
Thus, the efficiency of this solar panel is 12.5%, meaning that it can convert 12.5% of sunlight into usable energy.

How to Maintain your solar panel?

With proper maintenance, solar panels can generate efficient electricity for many years. To maintain and improve the efficiency of solar panels, there are some tips you need to know:

1. Clean solar panel regularly.

The gathering of debris, dust, or foreign objects on the panels' surface can hinder sun absorption efficiency. Frequent and thorough cleaning is necessary to maintain the effective conversion of solar energy to electrical energy.



2. Keep solar panel free shade.

If you keep solar panels shaded and prevent them from absorbing sunlight, their ability to produce energy will be reduced. To optimize energy production, it is important to ensure that solar panels are in direct sunlight and not in the shade.

3. Inspect your solar panel after extreme weather events

A severe storm, tornado, or hurricane can cause damage to solar panels, affecting their performance. You can easily detect issues by inspecting their appearance or monitoring their performance online.