Engineering Excellence for Empowerment

Nadar Saraswathi College of Engineering & Technology

NSCET E-LEARNING PRESENTATION

LISTEN … LEARN… LEAD…

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

IV YEAR / VII SEMESTER

EE8703 – RENEWABLE ENERGY SYSTEMS

B.SHANTHINI, M.Tech.,
Assistant Professor,
Nadar Saraswathi College of Engineering & Technology,
Vadapudupatti, Annanji (po), Theni – 625531.

UNIT 03

SOLAR PV AND THERMAL SYSTEMS

“Intellectuals solve problems, geniuses prevent them.”

—ALBERT EINSTEIN

SOLAR PV AND THERMAL SYSTEMS

Solar Radiation
Radiation Measurement
Solar Thermal Power Plant
Central Receiver Power Plants
Solar Ponds.
Thermal Energy storage system with PCM
Solar Photovoltaic systems : Basic Principle of SPV conversion
Types of PV Systems
Types of Solar Cells
Photovoltaic cell concepts: Cell, module, array ,PV Module I-V Characteristics, Efficiency & Quality of the Cell, series and parallel connections, maximum power point tracking, Applications.

Solar radiation

Solar radiation is radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy.

The spectrum of solar radiation is close to that of a black body with a temperature of about 5800 K. About half of the radiation is in the visible short-wave part of the electromagnetic spectrum.

The other half is mostly in the near-infrared part, with some in the ultraviolet part of the spectrum.

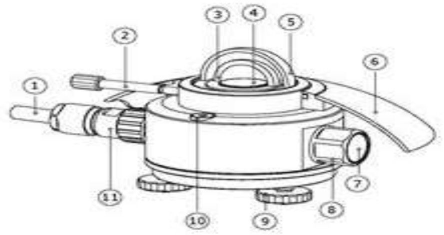
The units of measure are Watts per square meter.

A **solar radiation** sensor measures solar energy from the sun

Pyranometer

A **pyranometer** is a type of actinometer used for measuring solar irradiance on a planar surface and it is designed to measure the solar radiation flux density (W/m^2) from the hemisphere above within a wavelength range 0.3 μm to 3 μm. The name pyranometer stems from the Greek words (*pyr*), meaning "fire", and (*ano*), meaning "above, sky".

Thermopile pyranometers



Linedrawing of a pyranometer, showing essential parts: (1) cable, (3)pyranameter and (5) glass domes, (4) black detector surface, (6) sun screen, (7) desiccant indicator, (9) levelling feet, (10) bubble level, (11) connector

Photoelectric pyranometer - silicon photodiode

Pyrheliometer

A **pyrheliometer** is an instrument for measurement of direct beam solar irradiance. Sunlight enters the instrument through a window and is directed onto a thermopile which converts heat to an electrical signal that can be recorded. The signal voltage is converted via a formula to measure watts per square meter.

Typical pyrheliometer, for measurement of direct solar radiation

Application

Typical pyrheliometer measurement applications include scientific meteorological and climate observations, material testing research, and assessment of the efficiency of solar collectors and photovoltaic devices.

Solar thermal power plants

Most techniques for generating electricity from heat need high temperatures to achieve reasonable efficiencies.

The output temperatures of non-concentrating solar collectors are limited to temperatures below 200°C.

Concentrating systems must be used to produce higher temperatures. Due to their high costs, lenses and burning glasses are not usually used for large-scale power plants, and more cost-effective alternatives are used, including reflecting concentrators.

The reflector, which concentrates the sunlight to a focal line or focal point, has a parabolic shape; such a reflector must always be tracked.

In general terms, a distinction can be made between one-axis and two-axis tracking: one-axis tracking systems concentrate the sunlight onto an absorber tube in the focal line, while two-axis tracking systems do so onto a relatively small absorber surface near the focal point

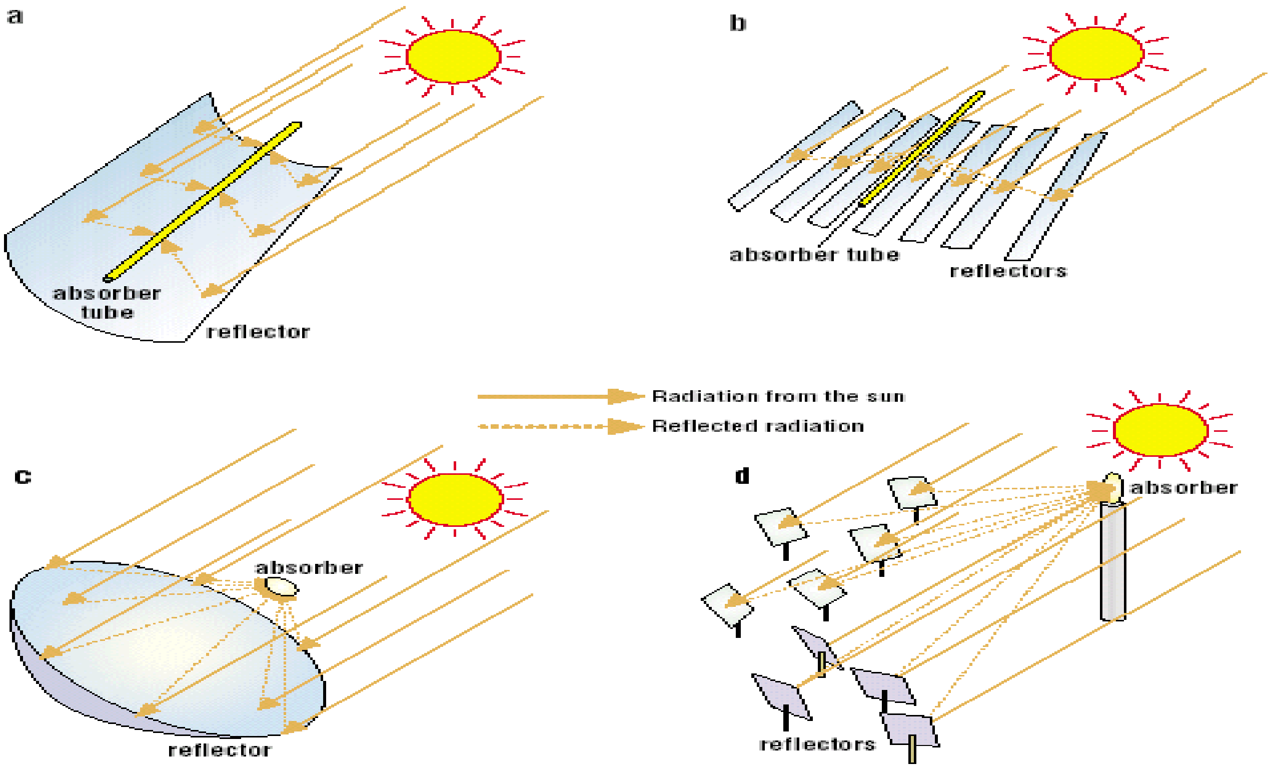


FIGURE 1. Concentration of sunlight using (a) parabolic trough collector (b) linear Fresnel collector (c) central receiver system with dish collector and (d) central receiver system with distributed reflectors

Parabolic Trough Power Plants

- The parabolic trough collector consists of large curved mirrors, which concentrate the sunlight by a factor of 80 or more to a focal line.
- Parallel collectors build up a 300–600 metre long collector row, and a multitude of parallel rows form the solar collector field.
- The one-axis tracked collectors follow the sun.

The collector field can also be formed from very long rows of parallel Fresnel collectors.

- In the focal line of these is a metal absorber tube, which is usually embedded in an evacuated glass tube that reduces heat losses.
- A special high-temperature, resistive selective coating additionally reduces radiation heat losses.

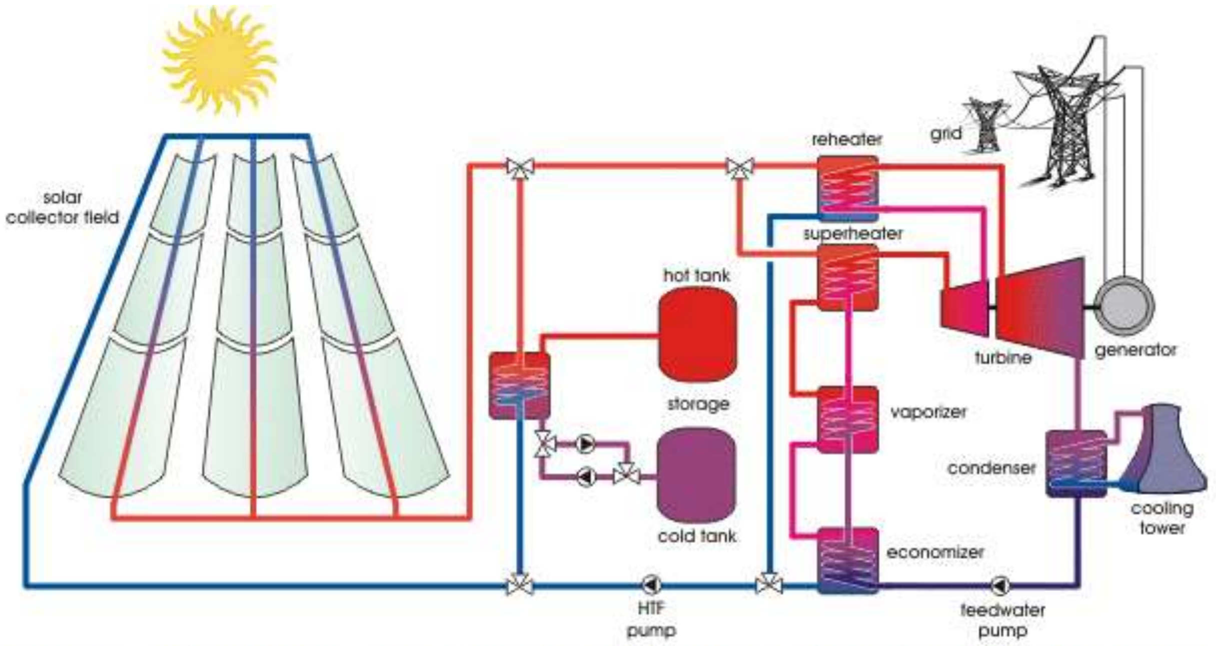
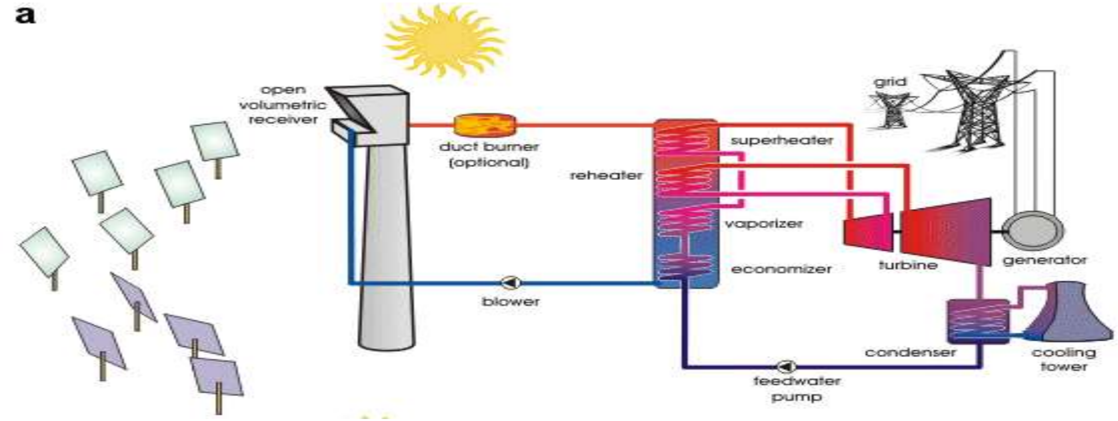


FIGURE 3. Schematic of a concentrated solar thermal trough power plant with thermal storage

Open Volumetric Air Receiver Concept

- The first type of solar tower is the open volumetric receiver concept
- A blower transports ambient air through the receiver, which is heated up by the reflected sunlight.
- The receiver consists of wire mesh or ceramic or metallic materials in a honeycomb structure, and air is drawn through this and heated up to temperatures between 650°C and 850°C
- On the front side, cold, incoming air cools down the receiver surface.
- The volumetric structure produces the highest temperatures inside the receiver material, reducing the heat radiation losses on the receiver surface.
- The air reaches the heat boiler, where steam is produced. A duct burner and thermal storage can also guarantee capacity with this type of solar thermal power plant.



Pressurized Air Receiver Concept

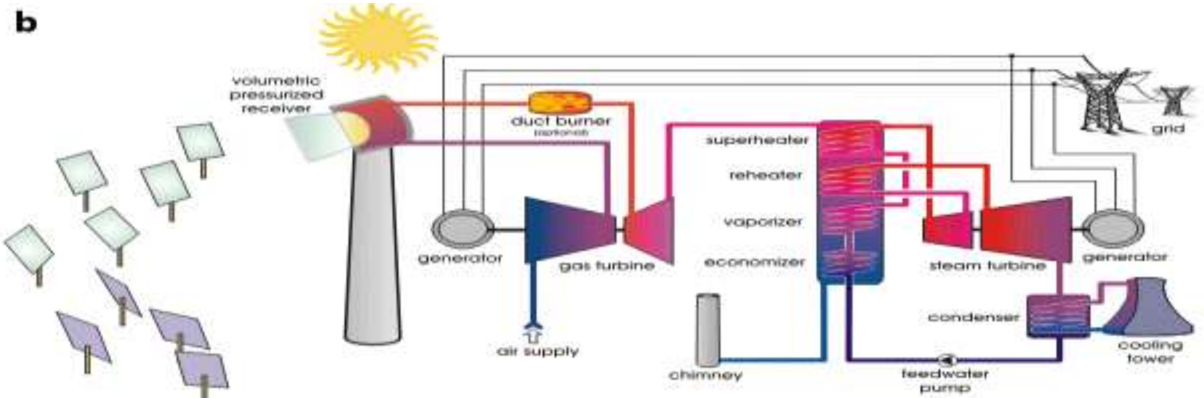
The volumetric pressurized receiver concept (see Figure 4b) offers totally new opportunities for solar thermal tower plants.

A compressor pressurizes air to about 15 bar; a transparent glass dome covers the receiver and separates the absorber from the environment.

Inside the pressurized receiver, the air is heated to temperatures of up to 1100°C, and the hot air drives a gas turbine.

This turbine is connected to the compressor and a generator that produces electricity. The waste heat of the gas turbine goes to a heat boiler and in addition to this drives a steam-cycle process.

The combined gas and steam turbine process can reach efficiencies of over 50%, whereas the efficiency of a simple steam turbine cycle is only 35%. Therefore, solar system efficiencies of over 20% are possible.



Dish-Stirling Systems

Dish–Stirling systems can be used to generate electricity in the kilowatts range.

A parabolic concave mirror (the dish) concentrates sunlight; the two-axis tracked mirror must follow the sun with a high degree of accuracy in order to achieve high efficiencies.

In the focus is a receiver which is heated up to 650°C. The absorbed heat drives a Stirling motor, which converts the heat into motive energy and drives a generator to produce electricity.

If sufficient sunlight is not available, combustion heat from either fossil fuels or biofuels can also drive the Stirling engine and generate electricity.

The system efficiency of Dish–Stirling systems can reach 20% or more. Some Dish–Stirling system prototypes have been successfully tested in a number of countries.

However, the electricity generation costs of these systems are much higher than those for trough or tower power plants, and only series production can achieve further significant cost reductions for Dish–Stirling systems.

Dish-Stirling prototype systems in Spain

Solar Chimney Power Plants

All three technologies described above can only use direct normal irradiance. However, another solar thermal power plant concept – the solar chimney power plant – converts global irradiance into electricity.

Since chimneys are often associated negatively with exhaust gases, this concept is also known as the solar power tower plant, although it is totally different from the tower concepts described above.

A solar chimney power plant has a high chimney (tower), with a height of up to 1000 meters, and this is surrounded by a large collector roof, up to 130 meters in diameter, that consists of glass or resistive plastic supported on a framework (see artist's impression). Towards its centre, the roof curves upwards to join the chimney, creating a funnel.

The sun heats up the ground and the air underneath the collector roof, and the heated air follows the upward incline of the roof until it reaches the chimney. There, it flows at high speed through the chimney and drives wind generators at its bottom.

The ground under the collector roof behaves as a storage medium, and can even heat up the air for a significant time after sunset.

The efficiency of the solar chimney power plant is below 2%, and depends mainly on the height of the tower, and so these power plants can only be constructed on land which is very cheap or free. Such areas are usually situated in desert regions.

CENTRAL RECEIVER

Central receiver (or power tower) systems use a field of distributed mirrors – heliostats – that individually track the sun and focus the sunlight on the top of a tower. By concentrating the sunlight 600–1000 times, they achieve temperatures from 800°C to well over 1000°C.

The solar energy is absorbed by a working fluid and then used to generate steam to power a conventional turbine.

The high temperatures available in solar towers can be used not only to drive steam cycles, but also for gas turbines and combined cycle systems. Such systems can achieve up to 35% peak and 25% annual solar electric efficiency when coupled to a combined cycle power plant.

The efficiency of these plants is usually better than Parabolic Trough plants, because fluid temperatures are higher – around 550°C. This leads to better thermodynamic performance and it also facilitates storage: smaller volumes are possible because of the higher temperature difference between the cold and the hot tanks.

SOLAR POND

- A **solar pond** is a pool of saltwater which collects and stores solar thermal energy. The saltwater naturally forms a vertical salinity gradient also known as a "halocline", in which low-salinity water floats on top of high-salinity water.
- The layers of salt solutions increase in concentration (and therefore density) with depth. Below a certain depth, the solution has a uniformly high salt concentration.

Advantages and disadvantages

- The approach is particularly attractive for rural areas in developing countries. Very large area collectors can be set up for just the cost of the clay or plastic pond liner.
- The accumulating salt crystals have to be removed and can be a valuable by-product and a maintenance expense.
- No need for a separate collector.
- The extremely-large thermal mass means power is generated night and day.
- Relatively low-temperature operation means solar energy conversion is typically less than 2%.[2]
- Due to evaporation, non-saline water is constantly required to maintain salinity gradients.

Solar PV Systems

Introduction to PV

Solar photovoltaic systems, commonly referred to as solar PV systems, convert sunlight directly into electricity.

This is different to the solar thermal collectors for solar water heaters. A solar PV system can help reduce carbon emissions and your electricity bill by producing sustainable electricity from the sun instead of burning fossil fuels.

Apricus offers a range of solar PV products to help you harness the power of the sun for commercial, industrial and residential electricity applications of all sizes.

Most electricity is distributed through an electrical utility provider, the company that produces and/or distributes electricity to consumers.

The electricity from a variety of sources is distributed along the electrical grid and can span hundreds of miles from the power plants to homes and businesses.

This grid network is not always reliable due to overloading, severe weather, and maintenance or upgrades. Installing a PV power system allows you to create your own electricity to supply your entire home or business and can potentially eliminate the issues associated with large utility grids.

The amount of electricity generated is dependent on several factors: the size and arrangement of the PV power system, the PV module type, the available sunlight, and the efficiency of the electrical components used to covert solar energy into electricity usable by your home or building.

Solar Photovoltaic Technology

Solar cells, also called photovoltaic cells, convert sunlight directly into electricity Photovoltaics (often shortened as PV) gets its name from the process of converting light (photons) to electricity (voltage), which is called the *photovoltaic effect*.

Silicon Solar Cells

These cells are usually assembled into larger modules that can be installed on the roofs of residential or commercial buildings or deployed on ground-mounted racks to create huge, utility-scale systems.

Thin-Film Solar Cells

They are made from very thin layers of semiconductor material, such as cadmium telluride or copper indium gallium dieseline. The thickness of these cell layers is only a few micrometers—that is, several millionths of a meter.

III-V Solar Cells

III-V solar cells are mainly constructed from elements in Group III—e.g., gallium and indium—and Group V—e.g., arsenic and antimony—of the periodic table. These solar cells are generally much more expensive to manufacture than other technologies. But they convert sunlight into electricity at much higher efficiencies. Because of this, these solar cells are often used on satellites, unmanned aerial vehicles, and other applications that require a high ratio of power-to-weight.

Next-Generation Solar Cells

Solar cells made from organic materials, quantum dots, and hybrid organic-inorganic materials .These next-generation technologies may offer lower costs, greater ease of manufacture, or other benefits. Further research will see if these promises can be realized.

Types of PV systems

There are three main types of solar PV and storage systems: grid-tied, grid/hybrid and off-grid. They all have their advantages and disadvantages and it really comes down to the customer’s current energy supply and what they want to get out of the system.

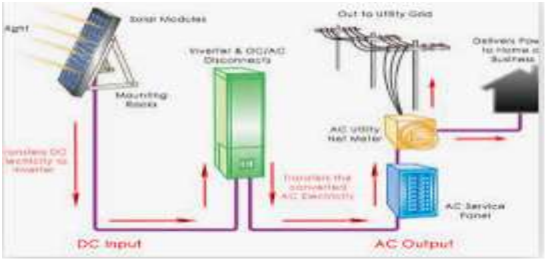
Grid-tied system

A grid-tied system is a basic solar installation that uses a standard grid-tied inverter and does not have any battery storage. This is perfect for customers who are already on the grid and want to add solar to their house.

These systems can qualify for state and federal incentives which help to pay for the system. Grid-tied systems are simple to design and are very cost effective because they have relatively few components. The main objective of a grid-tied system is to lower your energy bill and benefit from solar incentives.

One disadvantage of this type of system is that when the power goes out, so does your system. This is for safety reasons because linemen working on the power lines need to know there is no source feeding the grid.

Grid-tied inverters have to automatically disconnect when they don’t sense the grid. This means that you cannot provide power during an outage or an emergency and you can’t store energy for later use. You also can’t control when you use the power from your system, such as during peak demand time.



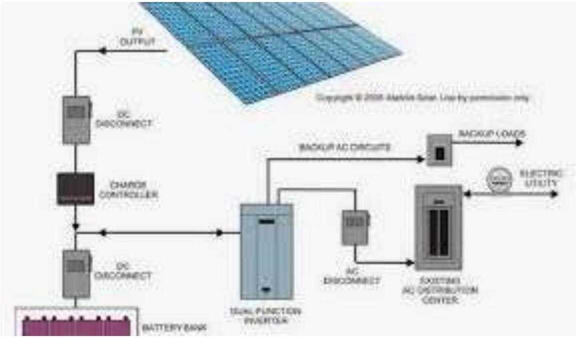
Nadar Saraswathi College of Engineering & Technology

Grid-tied system with battery back-up

The next type of system is a grid tied system with battery back-up, otherwise known as a grid-hybrid system. This type of system is ideal for customers who are already on the grid who know that they want to have battery back-up.

With this type of system, you get the best of both worlds because you're still connected to the grid and can qualify for state and federal incentives, while also lowering your utility bill. At the same time, if there's a power outage you have back up.

Battery based grid-tied systems provide power during an outage and you can store energy for use in an emergency. You are able to back up essential loads such as lighting and appliances when the power is out. You can also use energy during peak demand times because you can store the energy in your battery bank for later use.



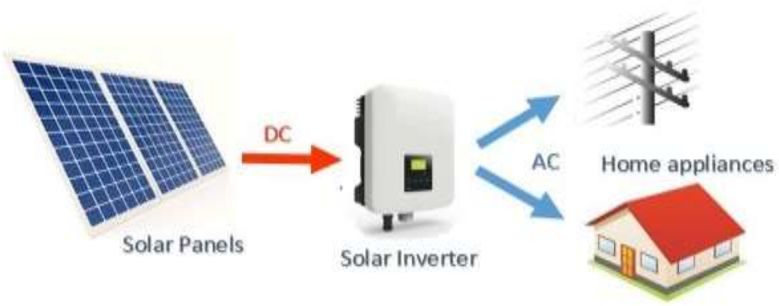
Off-grid system

Off-grid systems are great for customers who can’t easily connect to the grid. This may be because of geographical location or high cost of bringing in the power supply. In most cases, it doesn’t make much sense for a person connected to the grid to completely disconnect and do an off-grid system.

The benefits of an off grid system is that a person can become energy self-sufficient and can power remote places away from the grid. You also have fixed energy costs and won’t be getting a bill from your energy use.

Another neat aspect of off grid systems is that they are modular and you can increase the capacity as your energy needs grow. You can start out with a small, budget-conscious system and add on over time.

One disadvantage is that off-grid systems may not qualify for some incentive programs. You have to also design your system to cover 100% of your energy loads, and hopefully even a little bit more. Off-grid systems have more components and are more expensive than a standard grid-tied system as well.

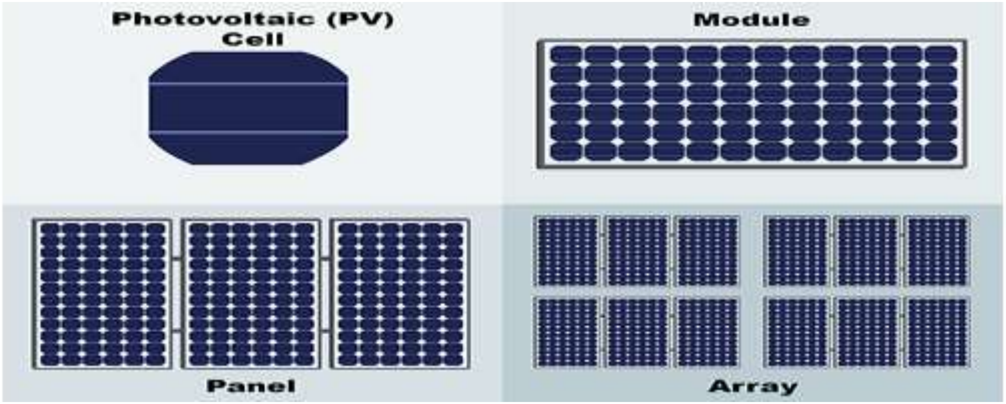


Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels.

Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building blocks of PV systems.

Photovoltaic panels include one or more PV modules assembled as a pre-wired, field-installable unit.

A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels.



Solar PV characteristics

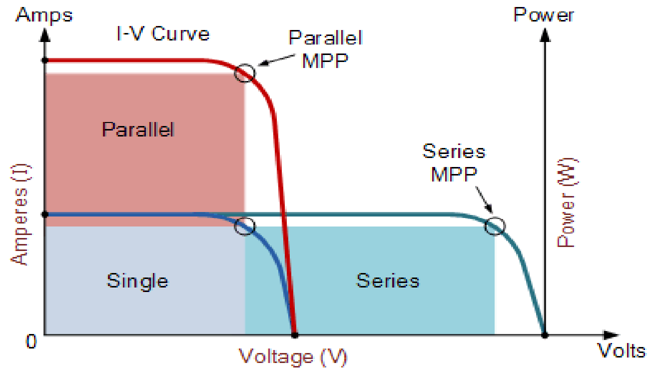
Photovoltaic panels can be wired or connected together in either series or parallel combinations, or both to increase the voltage or current capacity of the solar array.

If the array panels are connected together in a series combination, then the voltage increases and if connected together in parallel then the current increases.

The electrical power in Watts, generated by these different photovoltaic combinations will still be the product of the voltage times the current, (P = V x I).

However the solar panels are connected together, the upper right hand corner will always be the maximum power point (MPP) of the array.

Solar Panel I-V Characteristic Curves

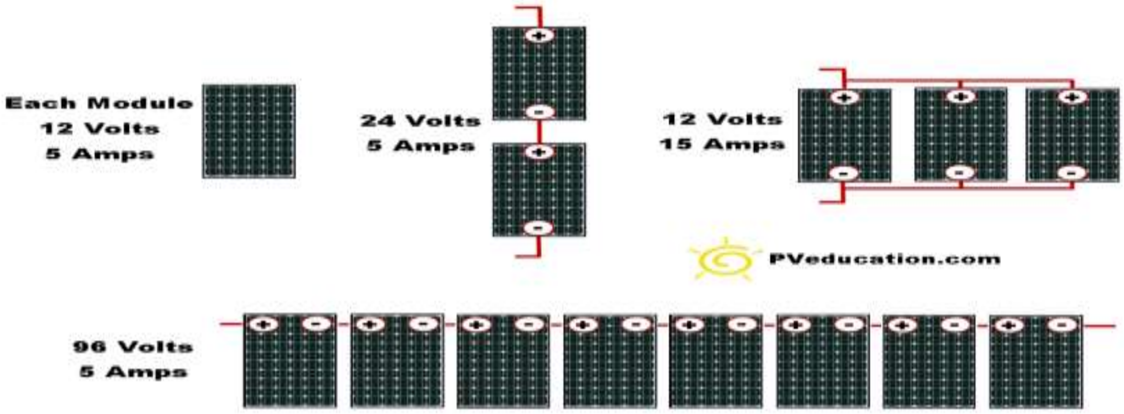


Series Wiring:

Series wiring is when the voltage of a solar array is increased by wiring the positive of one solar module to the negative of another solar module. This is similar to installing batteries in a flashlight. As you slide the batteries into the flashlight tube the voltage increases.

Parallel Wiring:

Parallel wiring increases the current (amps) output of a solar array while keeping the voltage the same. Parallel wiring is when the positives of multiple modules are connected together and all the negatives for the same modules are connected together.



Maximum power point tracking (MPPT)

Maximum power point tracking (**MPPT**) is a technique used commonly with wind turbines and photovoltaic (PV) solar systems to maximize power extraction under all conditions.

Although it primarily applies to solar power, the principle applies generally to sources with variable power: for example, optical power transmission and thermo photovoltaic's.

PV solar systems exist in many different configurations with regard to their relationship to inverter systems, external grids, battery banks, or other electrical loads. Regardless of the ultimate destination of the solar power, though, the central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels,

The temperature of the solar panel and the electrical characteristics of the load. As the amount of sunlight and temperature of the solar panel vary, the load characteristic that gives the highest power transfer efficiency changes, so that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency.

This load characteristic is called the *maximum power point* (MPP) and MPPT is the process of finding this point and keeping the load characteristic there.

Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out.

Solar cells have a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve.

It is the purpose of the MPPT system to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions.

MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

APPLICATION

Solar Farms

Many acres of PV panels can provide utility-scale power—from tens of megawatts to more than a gigawatt of electricity. These large systems, using fixed or sun-tracking panels, feed power into municipal or regional grids.

Remote Locations

It is not always cost-effective, convenient, or even possible to extend power lines to locations where electricity is needed. PV can be the solution—for rural homes, villages in developing nations, lighthouses, offshore oil platforms, desalination plants, and remote health clinics.

Stand-Alone Power

In urban or remote areas, PV can power stand-alone devices, tools, and meters. PV can meet the need for electricity for parking meters, temporary traffic signs, emergency phones, radio transmitters, water irrigation pumps, stream-flow gauges, remote guard posts, lighting for roadways, and more.

Power in Space

From the beginning, PV has been a primary power source for Earth-orbiting satellites. High-efficiency PV has supplied power for ventures such as the International Space Station and surface rovers on the Moon and Mars, and it will continue to be an integral part of space and planetary exploration.

Building-Related Needs

In buildings, PV panels mounted on roofs or ground can supply electricity. PV material can also be integrated into a building's structure as windows, roof tiles, or cladding to serve a dual purpose. In addition, awnings and parking structures can be covered with PV to provide shading and power.

Military Uses

Lightweight, flexible thin-film PV can serve applications in which portability or ruggedness are critical. Soldiers can carry lightweight PV for charging electronic equipment in the field or at remote bases.

Transportation

PV can provide auxiliary power for vehicles such as cars and boats. Automobile sunroofs can include PV for onboard power needs or trickle-charging batteries. Lightweight PV can also conform to the shape of airplane wings to help power high-altitude aircraft.