SOLAR ENERGY

Solar radiation, also known as the solar resource, refers to the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity. The solar spectral irradiance is a measure of the brightness of the entire Sun at a wavelength of light, and is expressed in Watt per square meter (W/m^2).

Various technologies are used to convert this energy into electricity. Photovoltaic (PV) and Concentrating Photovoltaic (CPV) systems utilise the sun irradiation, while the direct heat from the sun is used in Concentrating Solar Power (CSP) plants.

1. Photovoltaic solar power generation

1.1 Historic background

The photoelectric effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which today's photovoltaic technology is based. He later won a Nobel Prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954.

1.2 What is Photovoltaics (PV)?

Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that produces the photovoltaic effect. It is not the heat required form the sun, but the amount of irradiation available.

A semiconductor is a material with electrical conductivity due to electron flow (as opposed to ionic conductivity), intermediate in magnitude between that of a conductor and an insulator. Semiconductor materials are the foundation of modern electronics, including radio, computers, telephones, and many other devices. Such devices include transistors, solar cells, many kinds of diodes (including the light-emitting diode), the silicon controlled rectifier, and digital and analog integrated circuits. Similarly, semiconductor solar photovoltaic panels directly convert light energy into electrical energy. In a metallic conductor, current is carried by the flow of electrons. In semiconductors, current is often schematized as being carried either by the flow of electrons or by the flow of positively charged "holes" in the electron structure of the material.

Common semiconducting materials are crystalline solids, but amorphous and liquid semiconductors are also known. Silicon is used to create most semiconductors commercially. Crystalline solids are a class of solids that have regular or nearly regular crystalline structures. This means that the atoms in these solids are arranged in an orderly manner.

Dozens of other materials are used, including germanium, gallium arsenide, and silicon carbide. A pure semiconductor is often called an "intrinsic" semiconductor. The electronic properties and the conductivity of a semiconductor can be changed in a controlled manner by adding very small quantities of other elements, called "dopants", to the intrinsic material. In crystalline silicon typically this is achieved by adding impurities of boron or phosphorus to the melt and then allowing the melt to solidify into the crystal. This process is called "doping".

1.3 How do Photovoltaic (PV) cells generate electricity?

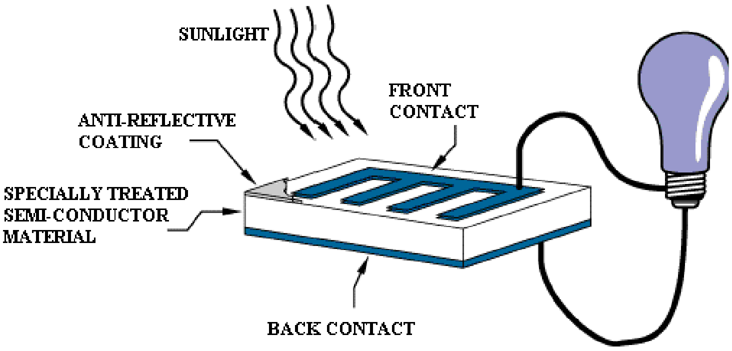
We cannot see electricity, therefore, we need to understand the science of how it is produced. In conventional power stations, Michael Faraday's principle of a magnet spinning inside a coil of wire is used. But, we also need to understand that in any which way we produce electricity, the role of atoms is important.

The atom:

- All matter is made up of atoms. Atoms are made up of smaller particles, including electrons.
- Electrons spin around the centre or nucleus of an atom, just as planets orbit the sun.
- Electrons have a negative charge.
- The nucleus is made up of neutrons and protons. Protons have a positive charge and neutrons are neutral.
- Some kinds of atoms have electrons that are loosely attached. They can easily be made to move from one atom to another. When these electrons move among the atoms of matter, a current of electricity is created.

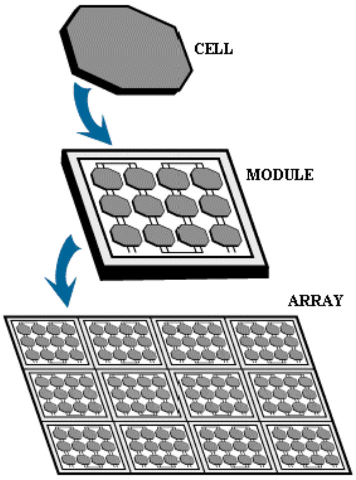
The photovoltaic effect refers to photons of light exciting electrons into a higher state of energy, allowing them to act as charge carriers for an electric current. The term photovoltaic denotes the unbiased operating mode of a photodiode; virtually all photovoltaic devices are some type of photodiode.

For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. Cells require protection from the environment and are usually packaged tightly behind a glass sheet. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current -- that is, electricity. This electricity can then be used to power a load, such as a light, a tool, etc.



A number of solar cells, electrically connected to each other and mounted in a support structure or frame, are called a PV module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volt system. The current produced is directly dependent on how much light (irradiation) strikes the module.

Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity will be produced. PV modules produce direct-current (DC) electricity. They can be connected in both series and parallel electrical circuits to produce the required voltage and current combination.

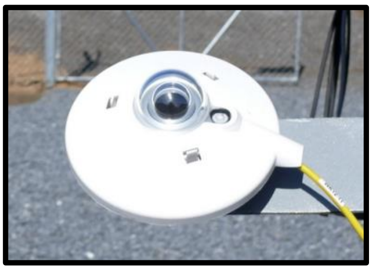


The first practical application of PV was to power orbiting satellites and other spacecraft, but today the majority of PV modules are used for grid connected power generation. In this case an inverter is required to convert the DC to alternating current (AC). There is a smaller market for off-grid power for remote dwellings, boats, recreational vehicles, electric cars, roadside emergency telephones, remote sensing and cathodic protection of pipelines. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and PV arrays has advanced considerably in recent years.

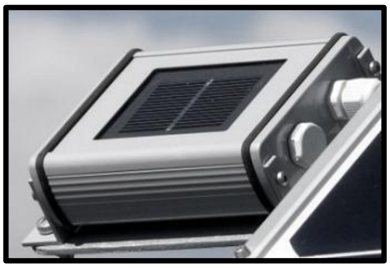
1.4 Basic control

An on-site meteorological station supplies data for the control of the plant. Wind speed is measured by an anemometer (a second anemometer is placed on the roof of the control station.) Wind direction measured by a wind vane and a rainfall meter is also supplied. Ambient temperature is also measured.

Two horizontal calibrated solar cells measure the irradiation available for the modules at horizontal and tilt plane. Two additional cells are placed on a tracker module, metering is for reference purposes. A pyranometer measures the irradiation onto the modules at all angles.



Pyranometer



Solar cells

All the information from these devices (calibrated solar cells and pyranometer) forms part of the control of the tracker system, i.e. it allows the tracker modules to follow the sun from east to west so power could be produced. The control system sends a signal to the hydraulic oil pumps which allows the tracker beams to move, i.e. follow the sun in accordance the available irradiation from the sun.

After sunset, the tracker modules move to the horizontal position. In an event of high winds, >50kmh, the second anemometer gives a signal for modules to move to the horizontal position (defensive mode) to protect the plant.

1.5 The Lethabo PV Plant

The construction of the Lethabo PV Plant started the first week of October of 2011. The plant went operational on 18 November 2011 and officially launched on 21 November 2011. It is a 575 kW plant constructed on a ± 0, 98 Hectares of land. It shows how quickly such a plant can be established, once all environmental, financial and other development approvals are obtained.

The Lethabo plant is of a single axis tracking structure. There are 1812 PV modules mounted on tracker beams. Each module comprises 96 cells and produces up to 318 W each. The capacity of each PV module is ± 318 W at 64, 7 Volt and a current of 6.2 Amps. The modules are of the Monocrystalline design.

All the tracker beams, 268 in total, are mounted on 340 poles fixed into the ground with concrete. The tracker beams are arranged in 18 rows and depending on the length of a row of beams; some are fitted with 7 PV modules whereas others have as many as 16 PV modules per tracker. The panels (modules) are constructed 1.6m above ground level. The plant structure faces north, with the PV modules face in an easterly direction. Each set of tracker beams is operated by hydraulic power cylinders, supplied by 10 hydraulic oil supply pumps. There are 71 hydraulic power cylinders.

The power produced a direct current (DC), leaves each PV module of a tracker beam and is connected in series to junction boxes (String boxes). The output form the junction boxes are connected in parallel and fed to an inverter where the power is converted to AC power.

The inverter has an input rating of 400 to 700 Volts DC at a current of 1145 Amps. The AC output is 500 to 550 kW, at ± 300 Volt and 955 Ampere. From the inverter, the power is stepped up to 11kV via a 630 kVA transformer and sent to the power stations services distribution boards from where power is fed to the main administration building.

The power production of a PV module is temperature dependent. The production lowers with increase in temperature. The plant is less efficient in summer due to high temperatures. Irradiation of 200W/m² is considered as bad irradiation. The PV system can still produce energy at as low as 60 W/m². Overall efficiency of the PV plant is 20%.

2. Concentration Photovoltaic (CPV)

A concentration photovoltaic (CPV) system converts light energy in a similar way than a PV system into electrical energy. The difference lies in the additional optical system (lenses or curved mirrors) that focuses a large area of sunlight onto each smaller cell. The optics in CPV accepts the direct component of sunlight light and therefore must be oriented appropriately to collect energy. Commercial CPV systems use dual axis solar trackers to follow the sun. Cooling systems could be used to further increase their efficiency.

3. Concentrating Solar Power (CSP)

The Concentrating Solar Power (CSP) technology has been identified as being potentially viable and capable of being employed on a large scale. The Northern Cape has an excellent solar resource when compared to other areas of the world and is considered suitable for CSP generation.

An example of a power plant using central receiver technology. This is a 10 MW demonstration plant that was built in the United States (image courtesy NREL).

Location	Site Latitude	Annual radiation (kWh/m^2)
Upington, Northern Cape	28°S	2,995
Barstow, California	35°N	2,725
Spain	34°N	2,100

3.1 How does a CSP Plant work?

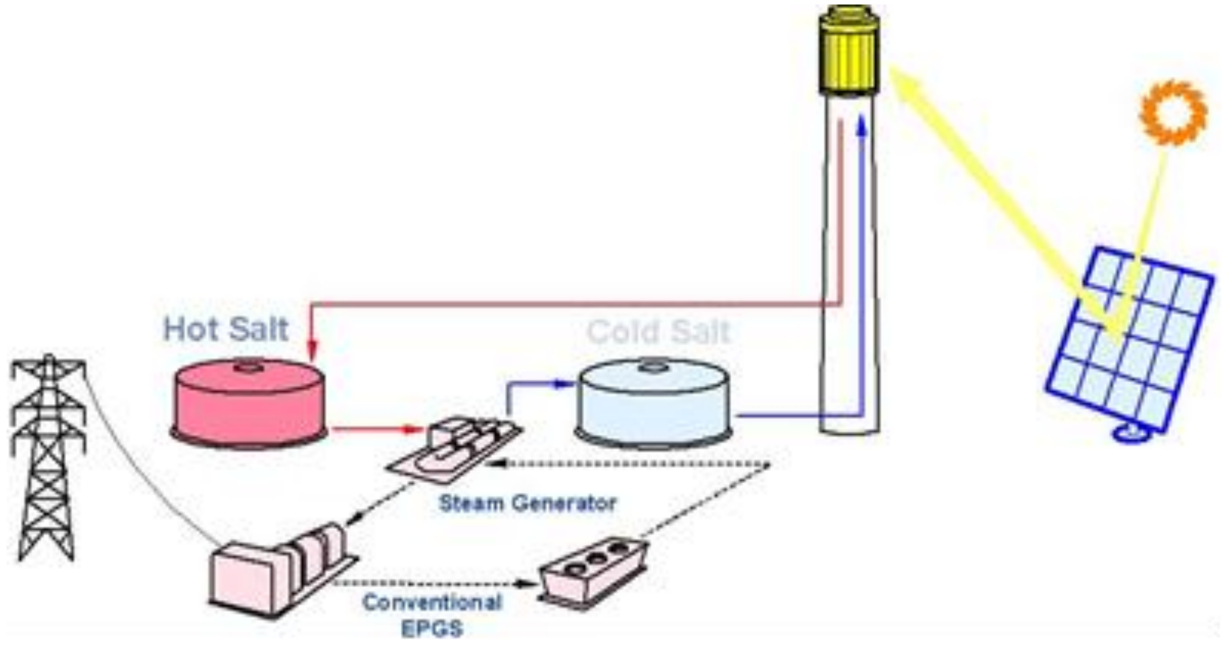
CSP is used to produce solar thermoelectricity by utilising a conventional steam generator. The CSP technologies include parabolic trough, dish, concentrating linear Fresnel reflector, and solar power tower technologies. It uses multiple mirrors and dual-axis tracker systems to concentrate the sunlight (heat) onto a small receiver. Parabolic trough systems focus the heat onto an insulated tube filled with synthetic oil to transport the heat to the plant. Large scale CSP power towers make use of thousands of large, dual-axis tracking mirrors (known as heliostats), which track the sun and reflect the beam radiation onto a common focal area (receivers) at the top of the tower.

The heliostat field is designed to prevent interference between the reflected radiation of the various heliostats. Heliostats are arranged in an elliptical formation around the focal point with the majority of the reflective area weight to the more effective side of the heliostat field (southern side in South Africa). It is estimated that approximately 6 000 heliostats at 120 m^2 each will be required within the heliostat field in order to obtain a power output of approximately 100 MW, while also enabling approximately 8 hours of energy storage.

The thermal energy stored at a CSP plant can be used to produce electricity when it is needed during day or night time. CSP generation from solar thermal energy storage is dispatchable and similar to coal and gas fired power plants. The CSP generation is a cleaner process and avoids the CO2 pollution.

The central tower is roughly > 200 m high for a 100 MW facility, with the central receiver taking up the top part of the structure. This receiver is a heat exchanger consisting of thin walled tubing which absorbs the concentrated beam radiation. The heat is transferred to the working fluid (the molten salt circulated through it) which in turn is used to generate steam. Electrical power is then generated through a Rankine cycle (steam turbine process).

The working fluid is a salt mix of 60:40 ratio of Sodium Nitrate (NaNO3) and Potassium Nitrate (KNO3) - a very safe and environmentally friendly substance, which is a solid at room temperature. The cold salt is pumped up the central tower at approximately 300°C and flows through the central receiver where it is heated to approximately 600°C, after which it can be stored for use in the conventional steam power generation process. 1 MWh requires approximately 5 m3 (roughly 10 tonnes) of stored hot salt.



The power tower central receiver molten salt system

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