Photovoltaic system

A **photovoltaic (PV) system** is composed of one or more solar panels combined with an inverter and other electrical and mechanical hardware that use energy from the Sun to generate electricity. PV systems can vary greatly in size from small rooftop or portable systems to massive utility-scale generation plants. Although PV systems can operate by themselves as off-grid PV systems, this article focuses on systems connected to the utility grid, or grid-tied PV systems.

How do these Systems Work?

The light from the Sun, made up of packets of energy called photons, falls onto a solar panel and creates an electric current through a process called the photovoltaic effect. Each panel produces a relatively small amount of energy, but can be linked together with other panels to produce higher amounts of energy as a **solar array**. The electricity produced from a solar panel (or array) is in the form of direct current (DC). Although many electronic devices use DC electricity, including your phone or laptop, they are designed to operate using the electrical utility grid which provides (and requires) alternating current (AC). Therefore, in order for the solar electricity to be useful it must first be converted from DC to AC using an **inverter**. This AC electricity from the inverter can then be used to power electronics locally, or be sent on to the electrical grid for use elsewhere.

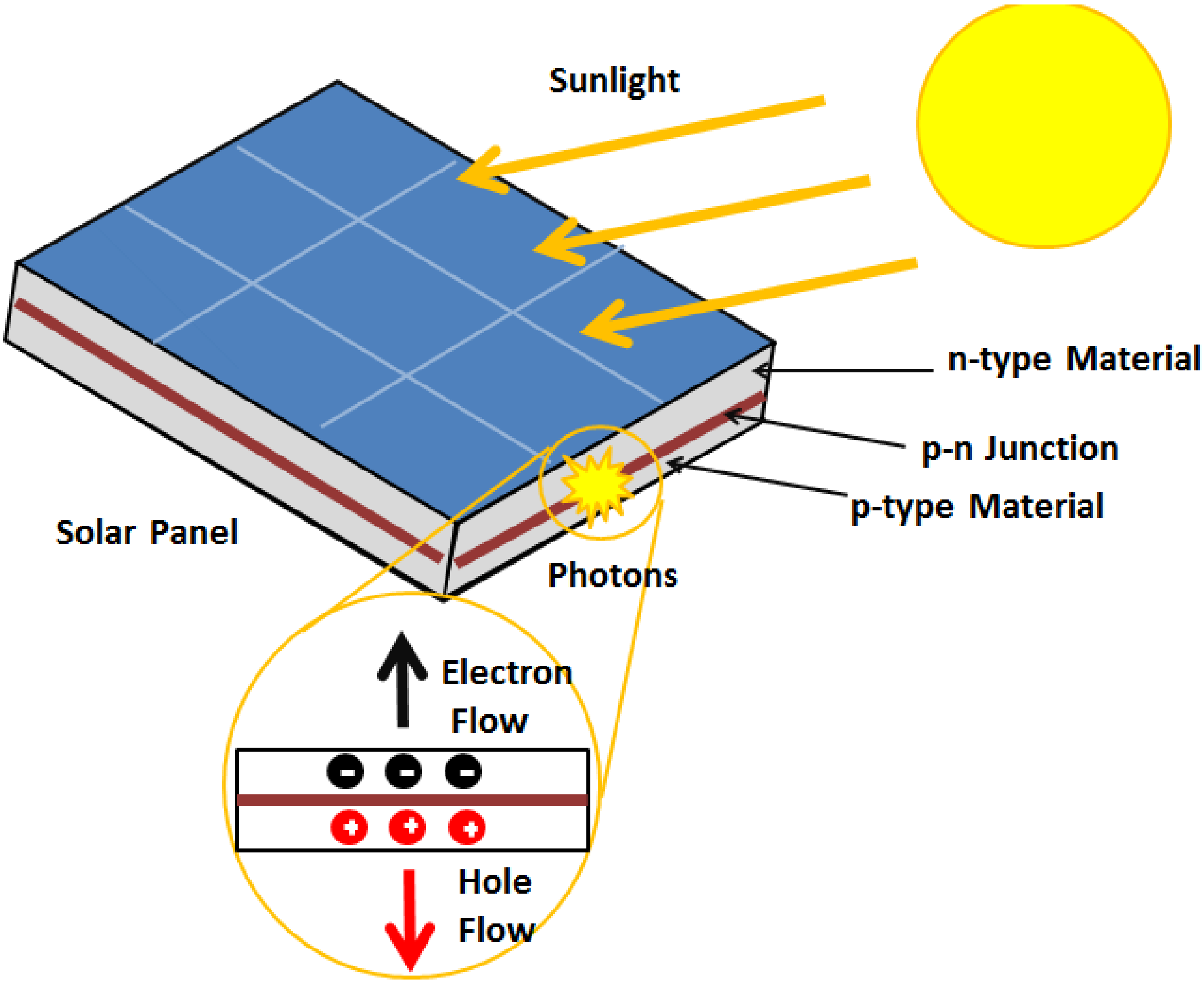
Photovoltaic effect

The **photovoltaic effect** is a process that generates voltage or electric current in a photovoltaic cell when it is exposed to sunlight. It is this effect that makes solar panels useful, as it is how the cells within the panel convert sunlight to electrical energy. The photovoltaic effect was first discovered in 1839 by Edmond Becquerel. When doing experiments involving wet cells, he noted that the voltage of the cell increased when its silver plates were exposed to the sunlight.

Process

The photovoltaic effect occurs in solar cells. These solar cells are composed of two different types of semiconductors - a p-type and an n-type - that are joined together to create a p-n junction. By joining these two types of semiconductors, an electric field is formed in the region of the junction as electrons move to the positive p-side and holes move to the negative n-side. This field causes negatively charged particles to move in one direction and positively charged particles in the other direction.

Light is composed of photons, which are simply small bundles of electromagnetic radiation or energy. These photons can be absorbed by a photovoltaic cell - the type of cell that composes solar panels. When light of a suitable wavelength is incident on these cells, energy from the photon is transferred to an atom of the semiconducting material in the p-n junction. Specifically, the energy is transferred to the electrons in the material. This causes the electrons to jump to a higher energy state known as the conduction band. This leaves behind a "hole" in the valence band that the electron jumped up from. This movement of the electron as a result of added energy creates two charge carriers, an electron-hole pair.



When unexcited, electrons hold the semiconducting material together by forming bonds with surrounding atoms, and thus they cannot move. However in their excited state in the conduction band, these electrons are free to move through the material. Because of the electric field that exists as a result of the p-n junction, electrons and holes move in the opposite direction as expected. Instead of being attracted to the p-side, the freed electron tends to move to the n-side. This motion of the electron creates an electric current in the cell. Once the electron moves, there's a "hole" that is left.[2] This hole can also move, but in the opposite direction to the p-side. It is this process which creates a current in the cell. A diagram of this process can be seen in Figure 1.

System Components

In addition to the solar panels, there are other important components of a photovoltaic system which are commonly referred to as the "balance of system" or BOS. These components (which typically account for over half of the system cost and most the of maintenance) can include inverters, racking, wiring, combiners, disconnects, circuit breakers and electric meters.

Solar Panel

A solar panel consists of many solar cells with semiconductor properties encapsulated within a material to protect it from the environment. These properties enable the cell to capture light, or more specifically, the photons from the sun and convert their energy into useful electricity through a process called the photovoltaic effect. On either side of the semiconductor is a layer of conducting material which "collects" the electricity produced. The illuminated side of the panel also contains an anti-reflection coating to minimize the losses due to reflection. The majority of solar panels produced worldwide are made from crystalline silicon, which has a theoretical efficiency limit of 33% for converting the Sun's energy into electricity. Many other semiconductor materials and solar cell technologies have been developed that operate at higher efficiencies, but these come with a higher cost to manufacture.

A **solar panel**, or **solar module**, is one component of a photovoltaic system. They are constructed out of a series of photovoltaic cells arranged into a panel. They come in a variety of rectangular shapes and are installed in combination to generate electricity.[2] Solar panels, sometimes also called *photovoltaics* collect energy from the Sun in the form of sunlight and convert it into electricity that can be used to power homes or businesses. These panels can be used to supplement a building's electricity or provide power at remote locations.

In addition to residential and commercial use, there is large-scale industrial or utility use of solar. In this case, thousands or even millions of solar panels are arranged into a vast solar array, or solar farm, which provides electricity to large urban populations.

What are Solar Panels Made of?

The main component of any solar panel is a solar cell. Specifically, a number of solar cells are used to build a single solar panel. These cells are the part of the device that convert the sunlight into electricity. Most solar panels are made from crystalline silicon type solar cells. These cells are composed of layers of silicon, phosphorous, and boron (although there are several different types of photovoltaic cells). These cells, once produced, are laid out into a grid pattern. The number of these cells used depends largely on the size of the panel being created, as many different sizing options exist.

Once the cells are laid out, the panel itself is sealed to protect the cells within and covered with a non-reflective glass. This glass protects the solar cells from damage, and is non-reflective to ensure sunlight can still reach the cells. Once sealed, this panel is placed into a rigid metallic frame. This frame is designed to prevent deformation, and includes a drainage hole to prevent water from building up on the panel as a buildup of water could reduce the efficiency of the panel. Additionally, the back of the panel is also sealed to prevent damage.

How Solar Panels Work

Solar panels act as a way to mount a series of solar cells so that their unique properties can be used to generate electricity. Individual cells absorb photons from the Sun, which results in the production of an electric current in the cell through a phenomenon known as the photovoltaic effect. An inverter is used to convert the direct current generated by a solar panel into alternating current. Combined, these two technologies create a photovoltaic system. When installing a solar panel, the proper orientation is chosen so that the solar panel faces in a direction that is most suitable for the specific application. This is most often to produce the maximum annual energy, but is not always the case.

Inverters

An inverter is an electrical device which accepts electrical current in the form of direct current (DC) and converts it to alternating current (AC). For solar energy systems, this means the DC current from the solar array is fed through an inverter which converts it to AC. This conversion is necessary to operate most electric devices or interface with the electrical grid. Inverters are important for almost all solar energy systems and are typically the most expensive component after the solar panels themselves.

Most inverters have conversion efficiencies of 90% or higher and contain important safety features including ground fault circuit interruption and anti-islanding. These shut down the PV system when there is a loss of grid power

Racking

Racking refers to the mounting apparatus which fixes the solar array to the ground or rooftop. Typically constructed from steel or aluminum, these apparatuses mechanically fix the solar panels in place with a high level of precision. Racking systems should be designed to withstand extreme weather events such as hurricane or tornado level wind speeds and/or high accumulations of snow. Another important feature of racking systems is to electrically bond and ground the solar array to prevent electrocution. Rooftop racking systems typically come in two variations including flat roof systems and pitched roof systems. For flat rooftops it is common for the racking system to include weighted ballast to hold the array to the roof using gravity. On pitched rooftops, the racking system must be mechanically anchored to the roof structure. Ground mounted PV systems, as shown in figure 4, can also use either ballast or mechanical anchors to fix the array to the ground. Some ground mounted racking systems also incorporate tracking systems which use motors and sensors to track the Sun through the sky, increasing the amount of energy generated at a higher equipment and maintenance cost.

Other Components

The remaining components of a typical solar PV system include combiners, disconnects, breakers, meters and wiring. A **solar combiner**, as the name suggests, combines two or more electrical cables into one larger one. Combiners typically include fuses for protection and are used on all medium to large and utility-scale solar arrays. **Disconnects** are electrical gates or switches which allow for manual disconnection of an electrical wire. Typically used on either side of an inverter, namely the "DC disconnect" and "AC disconnect" these devices provide electrical isolation when an inverter needs to be installed or replaced. Circuit breakers or **breakers** protect electrical systems from over current or surges. Designed to trigger automatically when the current reaches a predetermined amount, breakers can also be operated manually, acting as an additional disconnect. An **Electric meter** measures the amount of energy that passes through it and is commonly used by electric utility companies to measure and charge customers. For solar PV systems, a special bi-directional electric meter is used to measure both the incoming energy from the utility, and the outgoing energy from the solar PV system. Finally, the **wiring** or electrical cables transport the electrical energy from and between each component and must be properly sized to carry the current. Wiring exposed to sunlight must have protection against UV exposure, and wires carrying DC current sometimes require metal sheathing for added protection.