

## 3.7. What is solar photovoltaic (PV) systems?

The term "photovoltaic" comes from the Greek  $\phi\omega\varsigma$  (*phōs*) meaning "light", and from "volt", the unit of electromotive force, the volt, which in turn comes from the last name of the Italian physicist Alessandro Volta, inventor of the battery (electrochemical cell). The term "photovoltaic" has been in use in English since 1849 (WEB-1: *Photovoltaics*).

George Cove may have invented a photovoltaic panel in 1909, roughly 40 years before Bell Labs did in 1950 (WEB-1: *Photovoltaics*).

The utilization of photovoltaic (PV) devices to directly convert solar radiation into electricity is a rapidly advancing technology in the field of renewable energy. This is due to the increasing efficiency and decreasing cost of PV cells, as well as advancements in power electronics for the control and integration of PV systems into the electrical grid.

The photovoltaic effect, which is the basis for PV technology, refers to the phenomenon in which certain semiconducting materials exhibit a change in electrical potential when exposed to light. This effect is utilized in PV cells, which are typically composed of a p-n junction (a boundary between a p-type semiconductor and an n-type semiconductor) and an antireflection coating to increase the amount of light absorbed by the cell.

A PV system is composed of multiple PV modules, each of which contain multiple PV cells. These modules can be mounted on a variety of structures, including the ground, rooftops, walls, or floating platforms. The mount may also include a solar tracker, which adjusts the angle of the modules to optimize their exposure to sunlight throughout the day.

The electrical output of a PV system is affected by various factors, such as the intensity and spectral distribution of solar radiation, the temperature of the PV cells, and the shading and soiling of the modules. Power electronics are used to optimize the performance of the system by regulating the voltage and current of the electrical output and by providing protection against overvoltage and overcurrent conditions.

Additionally, the power generated by the PV system is fed into the electrical grid, and it is essential to ensure that the power generated is in phase and in sync with the grid voltage and frequency to prevent power quality issues and to comply with grid-connection standards.

### 3.7.1. The photovoltaic effect

Silicon solar cells, through the photovoltaic effect, absorb photons and generate flowing electricity. This process varies depending on the type of solar technology, but there are a few steps common across all solar PV cells (Marsh, J., 2022) (Fig. 3.7.1).

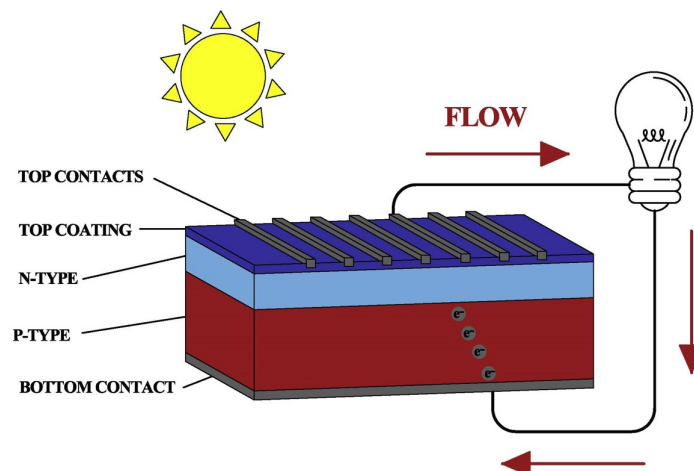


Fig.3.7.1. Solar cell structure. (Source: own elaboration).

**Step 1:** Light is absorbed by the PV cell and knocks the electrons loose.

First, light strikes a photovoltaic cell and the photons are absorbed by the semiconducting material it is made from (usually silicon). This incoming light energy causes electrons in the silicon to be knocked loose, which will eventually become the solar electricity you can use in your home (Marsh, J., 2022).

**Step 2:** Electrons begin to flow, creating an electrical current.

There are two layers of silicon used in photovoltaic cells, and each one is specially treated (known as “doping”) to create an electric field, meaning one side has a net positive charge and one has a net negative charge. This electric field causes loose electrons to flow in one direction through the solar cell, generating an electrical current (Marsh, J., 2022).

**Step 3:** The electrical current is captured and combined with other solar cells.

Once an electrical current is generated by loose electrons, metal plates on the sides of each solar cell collect those electrons and transfer them to wires. At this point, electrons can flow as electricity through the wiring to a solar inverter and then throughout your home (Marsh, J., 2022).

In a photovoltaic (PV) system, individual solar cells are electrically connected to form PV modules, which are then connected in series or parallel to form PV panels. These panels are then connected in series or parallel to form PV arrays, which increase the overall voltage and current output of the system. It is important to note that the efficiency of a PV module is typically lower than the efficiency of the individual cells within the module, and the efficiency of a PV array is typically lower than the efficiency of the individual modules within the array. This is due to factors such as shading, mismatch, and series resistance of the interconnections between cells, modules, and panels.

To achieve optimal performance, it is desirable to use identical cells within a module and identical modules within an array. This helps to minimize mismatch losses, which occur when different cells or modules within a system have different electrical characteristics. Additionally, using identical cells and modules allows for more precise prediction and control of the system's performance, as well as easier maintenance and replacement.

#### **Some other ways to achieve optimal performance:**

1. **Maximum Power Point Tracking (MPPT):** MPPT is a technique used to optimize the power output of a PV system by adjusting the operating point of the system to the point of maximum power.
2. **Temperature Compensation:** The performance of PV cells is affected by temperature, so it is important to monitor and adjust the system to compensate for changes in temperature.
3. **Shading Management:** shading can greatly affect the performance of a PV system, so it is important to minimize shading by optimizing the orientation and tilt of the PV modules, and by using shading devices such as bypass diodes.
4. **Module-level Power Electronics:** By using module-level power electronics, such as microinverters, it is possible to optimize the performance of each module individually, rather than treating the entire array as a single entity.
5. **Advanced modeling and simulation:** With the help of software simulation, a PV system can be modeled and analyzed to optimize the performance and predict the energy yield under different weather conditions, it also helps in identifying the best design for a given location.

### **3.7.2. PV cell technologies**

Solar panels are devices that convert sunlight into electricity by harnessing the photovoltaic effect. The most common material used for solar panel construction is silicon, which is a semiconductor material that exhibits the photovoltaic effect. There are three primary types of PV cell technologies that dominate the global market: monocrystalline silicon, polycrystalline silicon, and thin-film.

**Monocrystalline solar panels** are constructed from a single silicon crystal, grown using the Czochralski method. This process is energy-intensive and can be costly, but it results in cells with high efficiency (typically

around 15-20%) and a long lifespan. The cells are also visually uniform in appearance, and are typically cut from a cylindrical shape to a rectangular shape.

**Polycrystalline solar panels** are constructed from multiple small fragments of silicon that are melted and pressed into a mold. The resulting cells have lower efficiency (typically around 12-15%) compared to monocrystalline cells, but they are less expensive to produce. The cells are also visually distinct, with a characteristic speckled appearance.

**Thin-film solar panels** are constructed by depositing one or more layers of semiconductor material on a substrate. This can be done using a variety of techniques, such as chemical vapor deposition (CVD), physical vapor deposition (PVD), or spin-coating. The efficiency of thin-film cells is typically lower than that of crystalline cells (around 5-10%), but they are less expensive to produce, and can be flexible and lightweight. There are a variety of thin film technologies available, such as CdTe, a-Si, CIGS and perovskite.

**Multi-junction cells** are another type of solar cell that can be used to improve efficiency by using multiple semiconductor materials. These cells are able to absorb a wider range of wavelengths, which increases their ability to convert sunlight into electrical energy. Typically, multi-junction cells have higher efficiency than single junction cells, around 35-40%.

Additionally, the choice of which PV cell technology to use can depend on a variety of factors such as the installation site, cost, available space, required power, and expected lifespan. It's important to note that the efficiencies mentioned here are approximate and may be affected by factors such as temperature and irradiance level.

## References

1. Marsh, J. (2022). *How does a photovoltaic solar cell work?* [Online] Available from: <https://news.energysage.com/how-solar-photovoltaic-cells-work/> [Accessed 09.01.2023].
2. WEB-1: *Photovoltaics*. [Online] Available from: <https://en.wikipedia.org/wiki/Photovoltaics> [Accessed 09.01.2023].