Solar Cells

Clean, Free Energy from the Sun

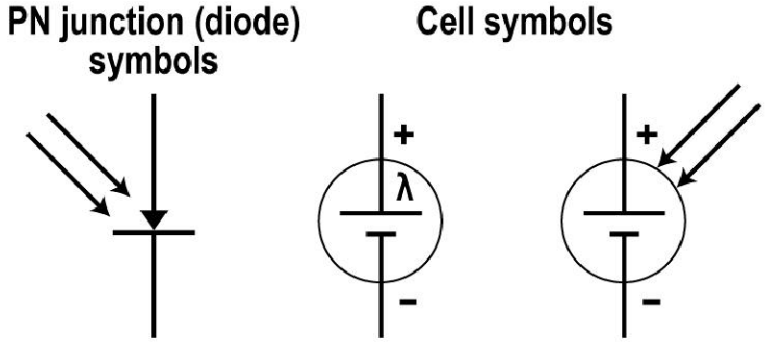
Solar Cells

A solar cell, also called a photovoltaic (PV) cell, is a light powered device that produces a DC output voltage. The PV cell converts light energy into electrical energy.

When sunlight or artificial light from a lamp strikes the surface of the PV cell, the cell produces a small voltage. This voltage is usually in the 0.3 to 1.5 volt range depending upon the load.

The amount of voltage and current produced is directly proportional to the surface area of the cell and the intensity of the light striking the cell.

Solar Cell Schematic Symbols

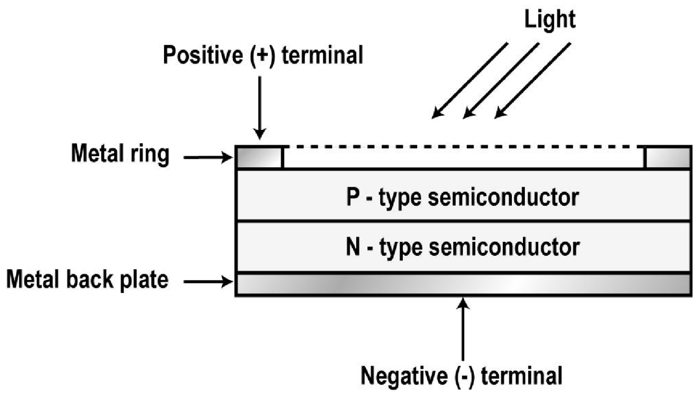


Arrows indicate light.
λ is lamda the Greek symbol for light and wavelength

Because of the low output voltage and current ratings for PV cells, they are usually connected in series and parallel combinations to form solar arrays or modules.

The figure above shows the schematic symbols used to represent a solar cell.

Solar Cell Structure

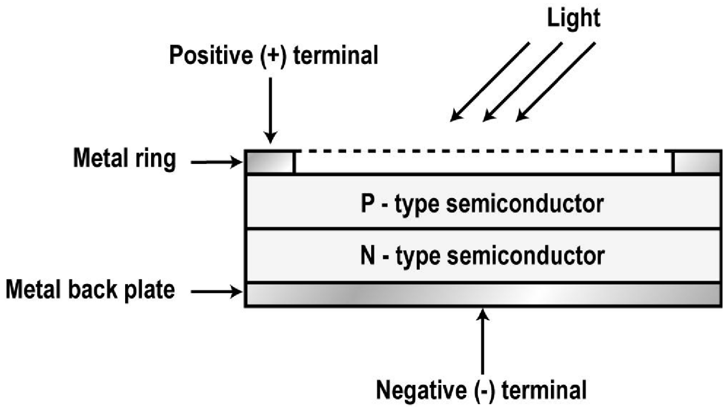


Most photovoltaic cells are made with silicon. Early PV cells were made with selenium but these are no longer widely used because silicon is a more efficient electrical energy producer.

The PV cell is a semiconductor device made with silicon and P-type and N-type semiconductor material.

The structure of a PV cell is a PN junction as shown above. The N-type material is the base and forms the negative terminal of the cell. The P-type material is exposed to the light and is the positive terminal of the cell.

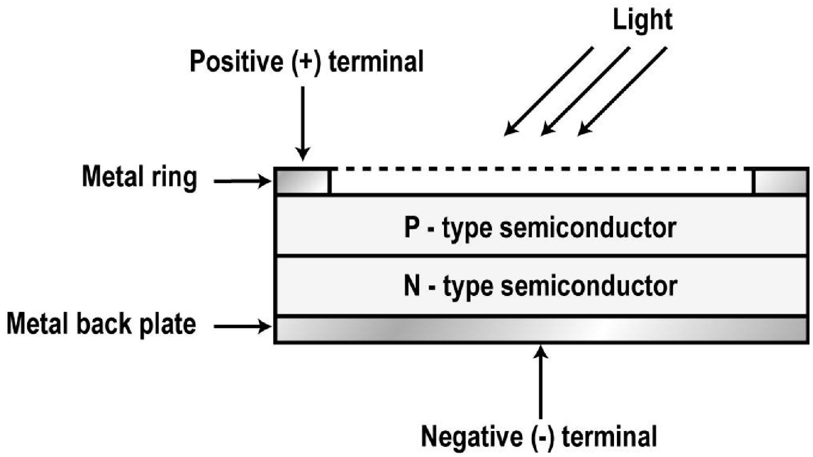
Solar Cell Structure



The PV cell is actually a PN junction diode that generates a DC voltage when exposed to the light. With no light, the PN junction acts just like an unbiased diode with a depletion region around the junction and an electric field.

Light energy, in the form of photons or packets of light energy impinging on the junction, produces electron-hole pairs and minority carriers, holes in P-type and electrons in the N-type.

Solar Cell Structure



Electrons flow from the P to the N material while holes flow from N to P.

When a load is connected, electrons flow from the N material through the load to the P material.

Metal contacts on the P and N material provide connections to the outside world.

Measures of Light Characteristics

Light characteristics are measured in intensity, frequency, wavelength, and visible light.

Light intensity is a measure of how much light is reaching the cell. The most common measure is the foot-candle (fc).

One fc is an intensity of one lumen of light per square foot of surface area illuminated by one international candle of light from a distance of one foot.

An international candle is actually a very specific type of candle used in establishing the standard.

Full sunlight is generally assumed to be about 2000 fc.

Light Intensity: Air Mass Units

Another measure of light intensity used with solar cells is air mass units.

Air mass 0 (AM0) is the amount of sun falling on a surface outside the earth's atmosphere.

AM1 is the amount of light falling on a surface at sea level when the sun is directly overhead and the atmosphere clear.

A more realistic measure is AM2 which is the sunlight falling on a surface through normal atmosphere. The rating is given in the amount of power produced by the solar cell in terms of kilowatts per square meter of area or kW/m^2.

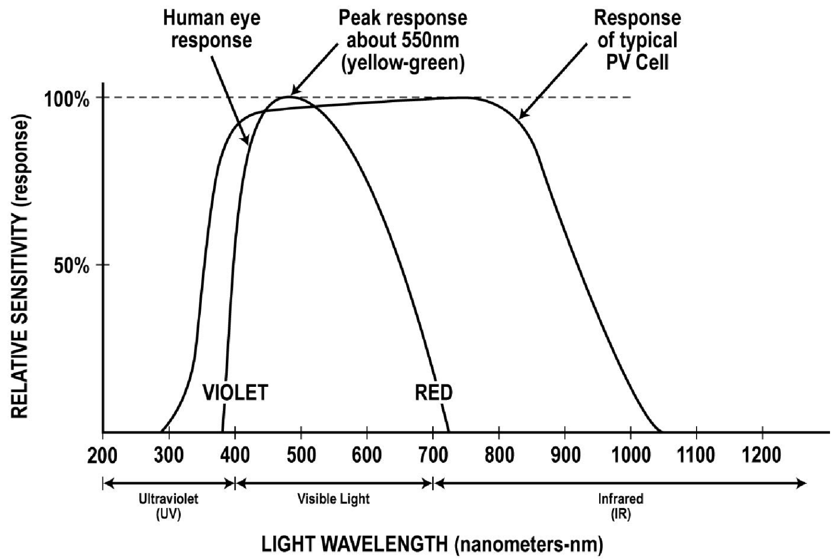
AM2 = 0.8 kW/m^2 and AM1 = 1 kW/m^2.

Light Frequency and Wavelength

Light is an electromagnetic radiation like a radio wave so it has both a frequency and wavelength (λ). Because the light frequencies are so high, we normally use wavelength to designate light frequency or color.

Light wavelengths are usually given in microns, nanometers, or angstroms. A micron (μ) is one millionth of a meter or 10^{-6} meter. A nanometer (nm) is one billionth of a meter or 10^{-9} meter. There are 1000 (10^3) nanometers in one micron. An angstrom (Å) is 10^{-10} meter. The most commonly used measure today is nm.

Visible Light



Visible light extends from 400 nm (violet) to 700 nm (red). Values above approximately 800 nm are referred to as infrared (IR). Those below 400 nm are referred to as ultraviolet (UV).

The figure above shows the visible light spectrum that humans see.

Solar Cell Specifications: V_{OC} and I_{SS}

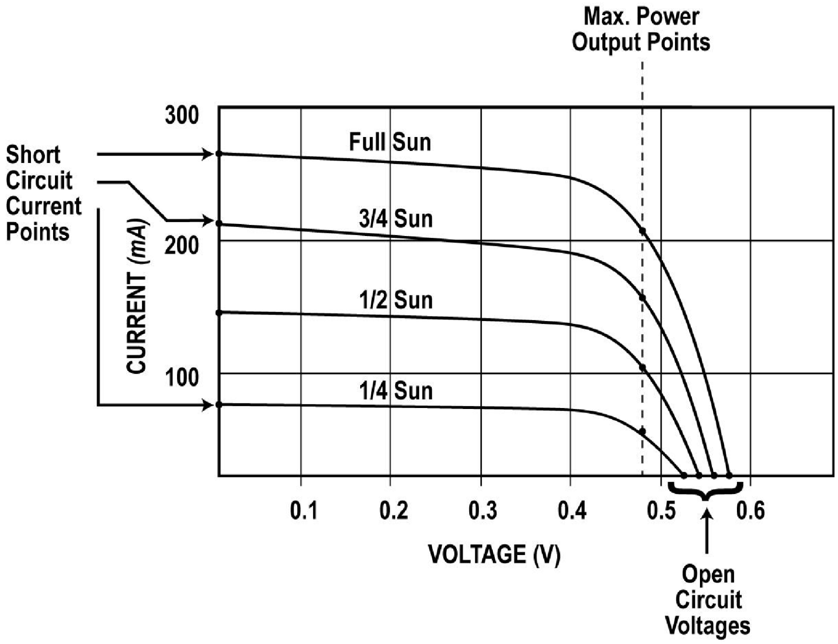
Open circuit voltage (V_{oc}) is the voltage produced by the cell with no load attached. It is dependent upon the surface area of the cell and the amount of light striking it. Typical values for silicon cells are in the 0.3 to 0.6 volt range.

The short circuit current (I_{sc}) is the maximum amount of current that the cell can supply with a shorted load. This value is also dependent upon the surface area of the cell and the amount of light striking it.

Small cells have a shorted current in the 5 to 40 mA range with full sunlight but larger cells can produce several amperes of current. A general rule of thumb is that the common PV cell produces about 40 mA per square centimeter (cm^2) of area when illuminated by full sunlight.

There is no damage to the cell if shorted to test for maximum current.

Solar Cell Specifications: V-I Plot



The voltage-current (V-I) plot of the solar cell output shows the output voltage is less affected by the light intensity than the current capability. With less light, the output voltage remains essentially the same but the current capacity is greatly curtailed.

Solar Cell Specifications: Internal Resistance and Spectral Response

The internal resistance (R_s) is the actual operating resistance of the cell as it supplies power to a load. It is the resistance of the voltage source that appears in series with the load.

It is calculated with the simple formula: $R_s = V_{oc}/I_{sc}$

The spectral response is the performance of the cell as determined by the frequency (or wavelength) of the light. Most silicon cells give peak output at about 800 to 900 nanometers (nm) but produce excellent output over the full range of the visible light spectrum.

Solar Cell Applications

The most common application of solar cells is their use in recharging secondary batteries. This includes marine batteries at sea, batteries that power space craft and satellites, and batteries in telemetry or other communications equipment in very remote locations.

They are used any place where electricity is not generally available.

They are also used in home or business power where large solar panels are used to supply power and/or recharge batteries. These panels, in turn, are used to supply all or part of the electricity to the home or business.

Charging Lead Acid Batteries

Solar panels are also used to recharge common lead-acid batteries.

These 12 volt lead-acid batteries must be recharged by a voltage source that is greater than open circuit battery output when charged. For a 12 volt battery, a recharging voltage in the 14 to 16 volt range is normally used.

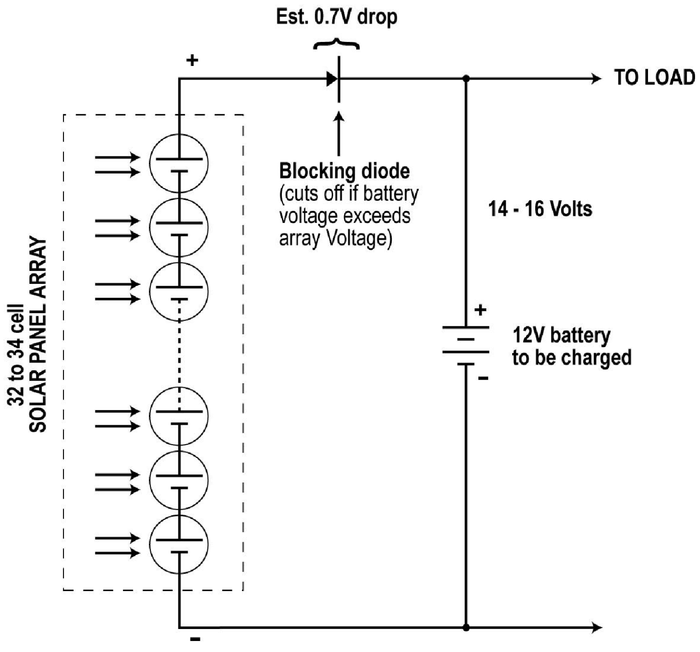
Assuming a nominal 0.5 volt output from each cell, then the charging solar panel must have about 32-34 cells to produce 16 to 17 volts. A 33 cell panel is common.

Battery Charging

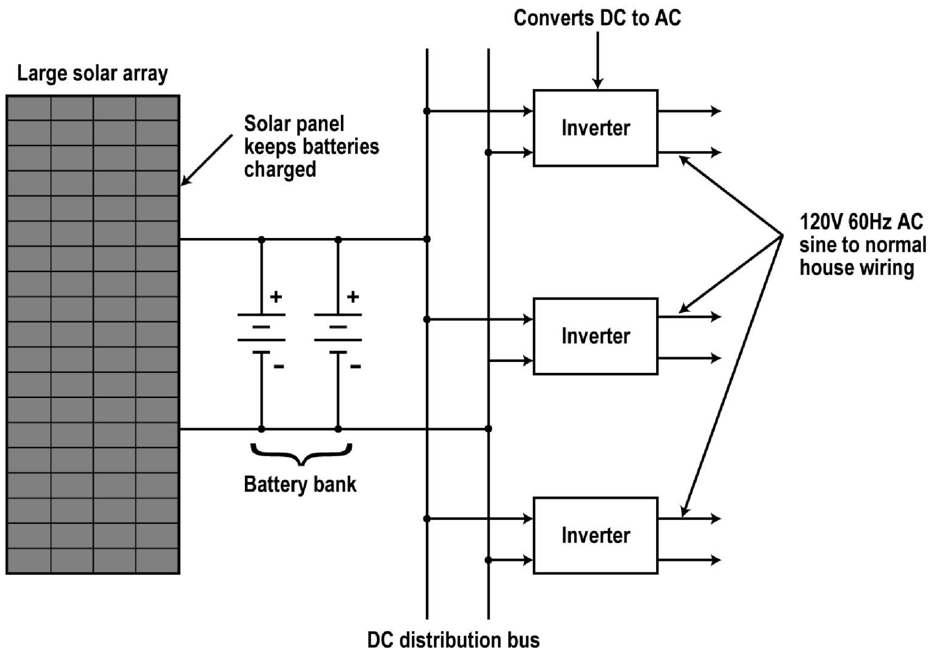
To charge the battery, the panel is connected directly across the battery in series with a blocking diode. This diode prevents the battery from discharging into the solar array when no sunlight is striking it.

Under these conditions, the solar array looks like a forward biased diode.

The blocking diode has a voltage drop in the 0.6 to 1.0 volt range depending upon its current rating.

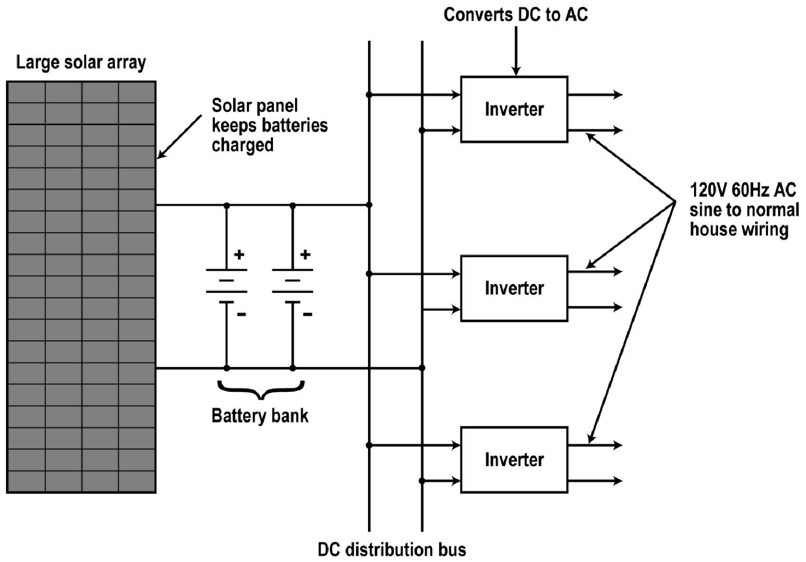


Home or Business Power System



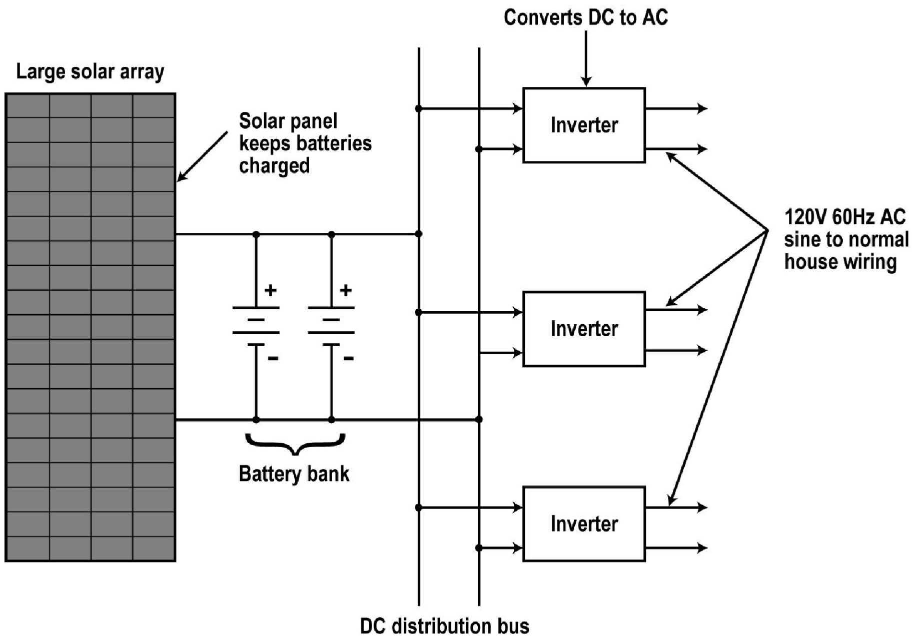
In a typical home or business electrical system, a large solar array keeps a set of storage batteries (usually lead-acid) charged.

Inverter Units



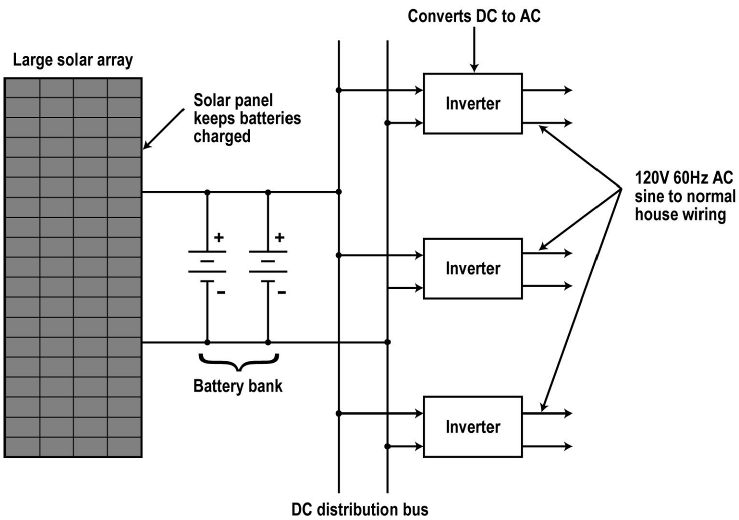
The batteries supply DC power to one or more inverter units. An inverter is an electronic circuit that converts DC to AC, usually 120 volt 60Hz. This AC is distributed to the home outlets, lights, and appliances through the traditional wiring as in any home.

Solar Array



The size of the solar array, number of batteries, and the sizes and number of inverters is determined by the overall power usage.

System Disadvantages



Such systems are not as economical as being tied to the standard electric power grid.

These systems work well only in areas of the country where sufficient sunshine occurs on a regular daily basis. This is usually the southern states such as Florida, Texas, Arizona, etc.

Testing Solar Cells

The usual test for solar cells is to first illuminate the cell or panel then test for output voltage and short circuit current. Direct sunlight should be used if available. If not, a good artificial light source is an EHL reflector type slide projector bulb. It closely simulates AM2 conditions when placed about 35 cm from the solar cell or panel.

The open circuit voltage can be measured with any standard DC multimeter. The output should be about 0.6 volts. The output of a panel or array depends upon the number of cells used. Check the specifications for details.

To measure short circuit output current, illuminate the cell as described above and connect an ammeter directly to the cell and read the rated output current. Check the cell specs for the correct value.

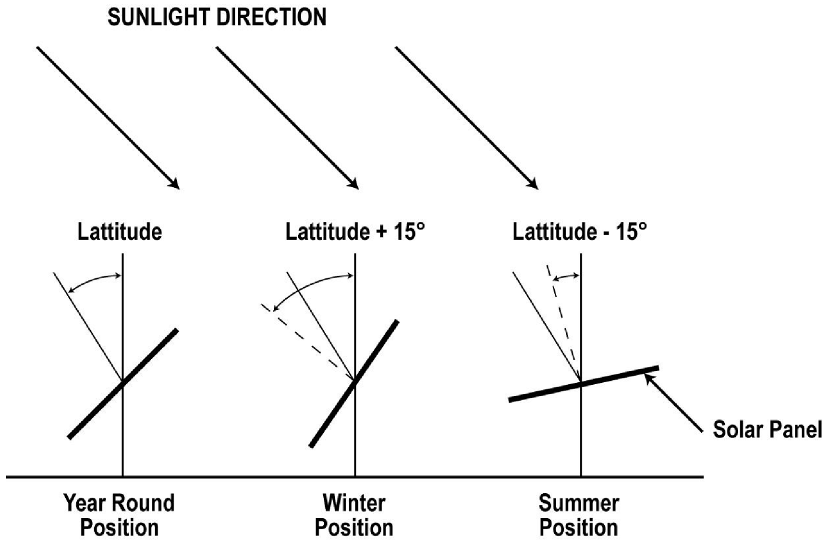
Orienting Solar Cells

Obviously, the solar panel produces maximum power when pointed directly at the sun. However, since the sun changes positions during the day, the power output will vary.

Sophisticated solar systems have a tracking system that measures the DC output and uses it as a feedback signal in a control system. The control system uses motors to change the position of the solar array automatically as the sun tracks across the sky.

Such systems maximize the power output. However, they are very expensive and only used in highly specialized situations.

Common Orientation



The most common orientation is a fixed position where the solar array is faced directly south with a tilt angle equal to the latitude of the location. For example, if you are in Washington, D.C., the latitude is 39°N. The solar panel should have that vertical setting as shown above. That setting is good all year, but if you wish to optimize the output for different seasons, add 15° to the tilt in the winter or subtract 15° tilt in the summer as the illustrations show.

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