Off-grid Power for Wireless Networks

Training materials for wireless trainers

The Abdus Salam International Centre for Theoretical Physics

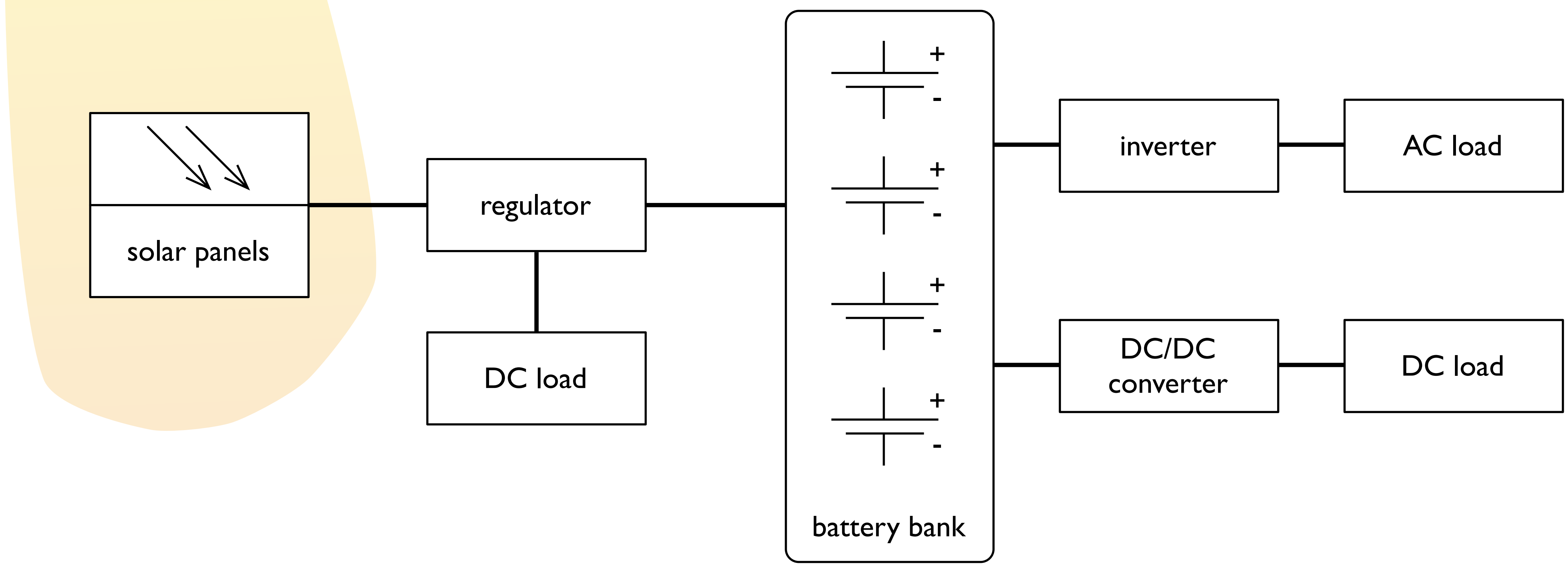
United Nations Educational, Scientific and Cultural Organization

Goals

- Provide a general view of the parts that comprise a solar photovoltaic system for telecommunication
- Understand the variables that affect the performance of a such a system
- Examine briefly the use of wind electrical generators

Photovoltaic system

A basic photovoltaic system consists of five main components: the ***sun***, the ***solar panel***, the ***regulator***, the ***batteries***, and the ***load***. Many systems also include a ***voltage converter*** to allow use of loads with different voltage requirements.



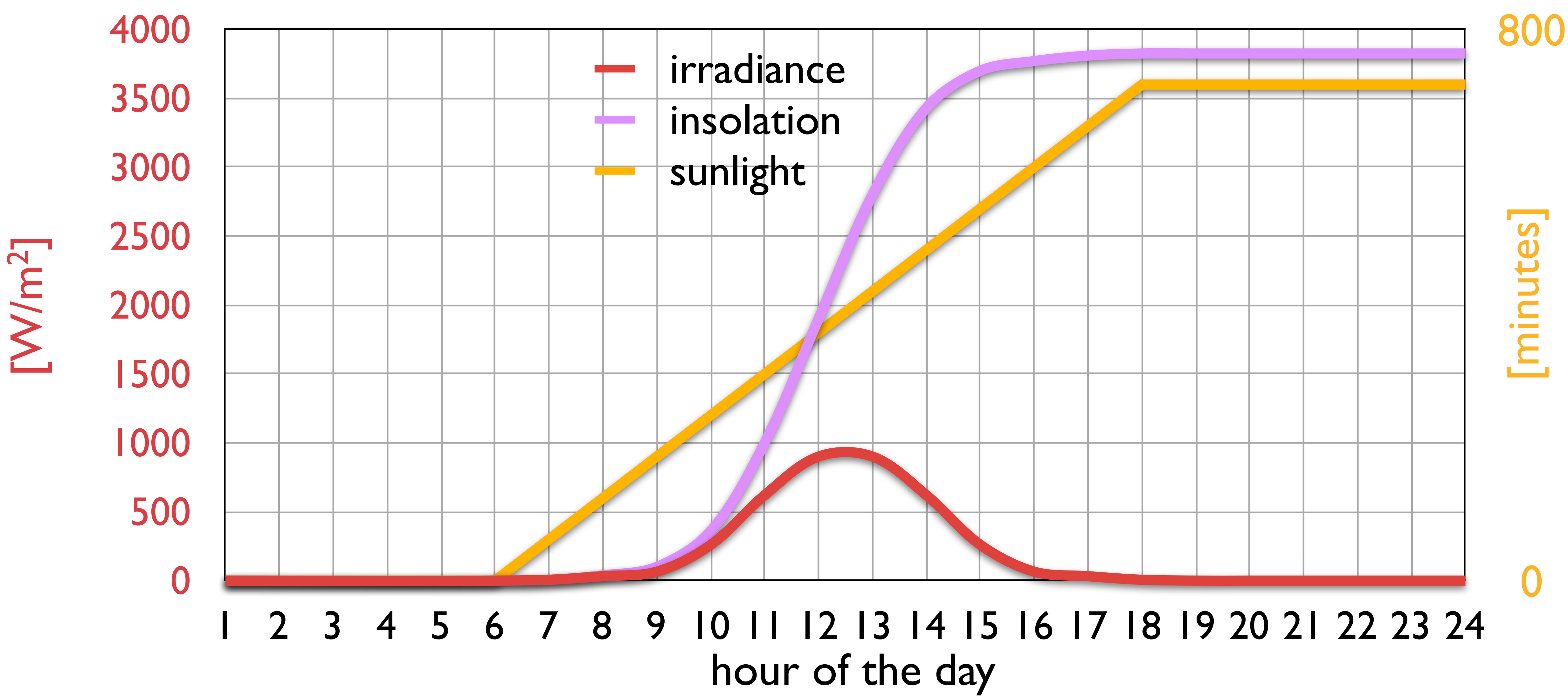
Solar power

A photovoltaic system is based on the ability of certain materials to convert the electromagnetic energy of the sun into electrical energy. The total amount of solar energy that lights a given area per unit of time is known as ***irradiance*** and it is measured in ***watts per square meter*** (***W/m^2***).

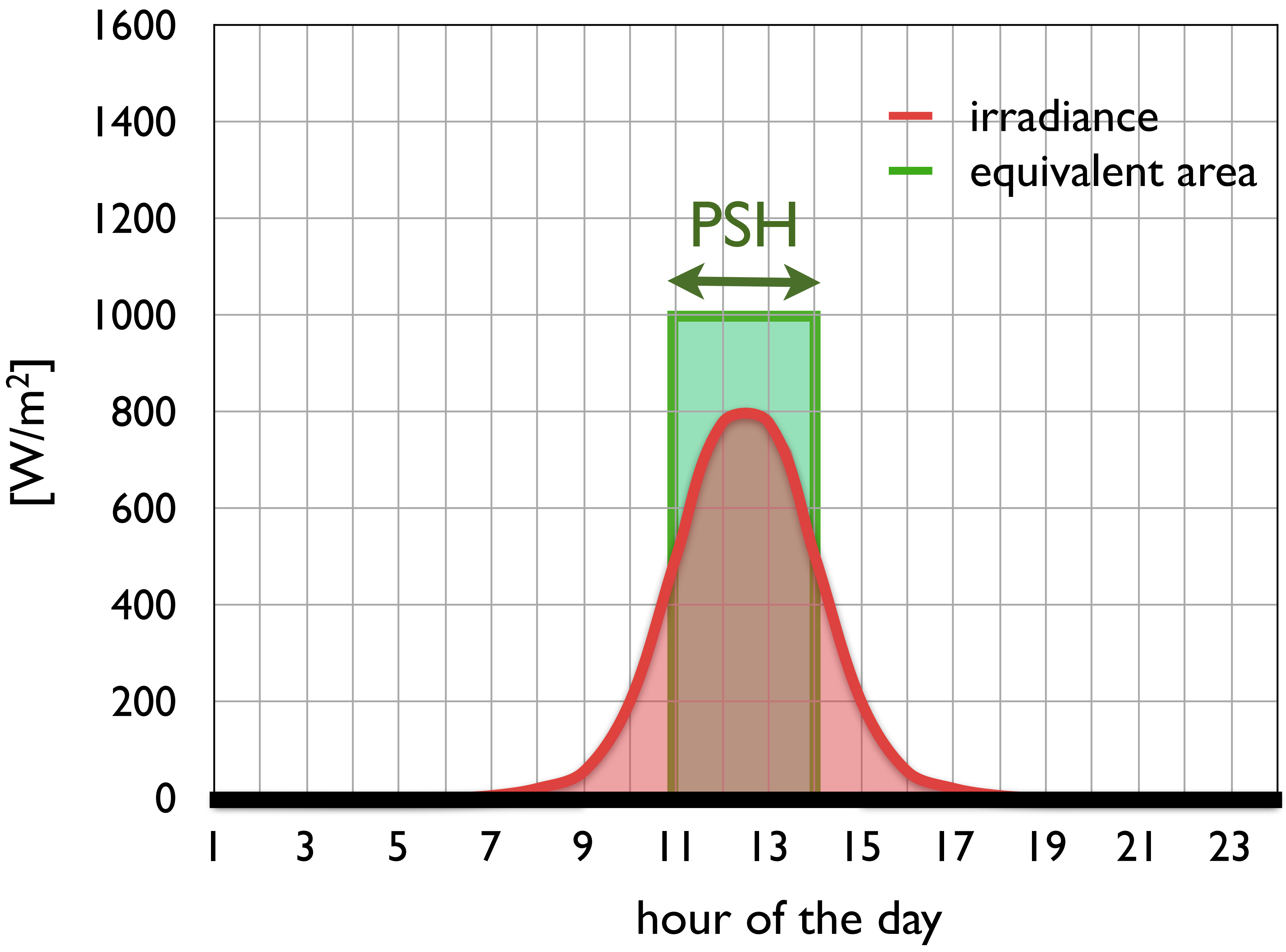
This energy is normally averaged over a period of time, so it is common to talk about total irradiance per hour, day or month.

Irradiance, irradiation, and sunlight

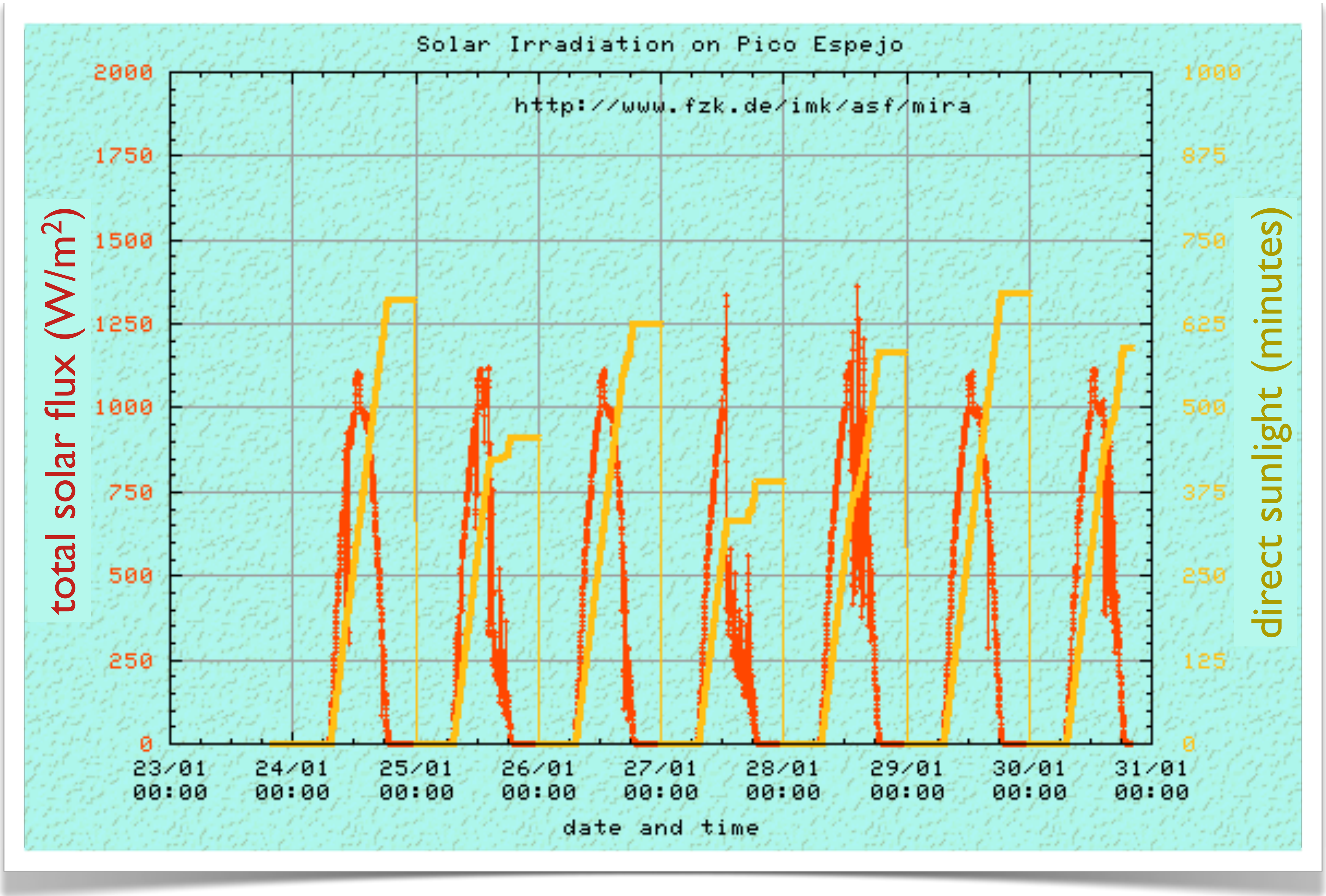
This graph shows **solar irradiance** (in W/m^2), **insolation** (cumulative irradiance) and **sunlight** (in minutes):



Peak Sun Hours



Real data: irradiance and sunlight



Peak sun hours

A few organizations have produced maps that include average values of daily global irradiation for different regions. These values are known as ***peak sun hours*** or ***PSH***s.

You can use the PSH value for your region to simplify your calculations. One unit of "peak sun" corresponds to a radiation of 1000 watts per square meter.

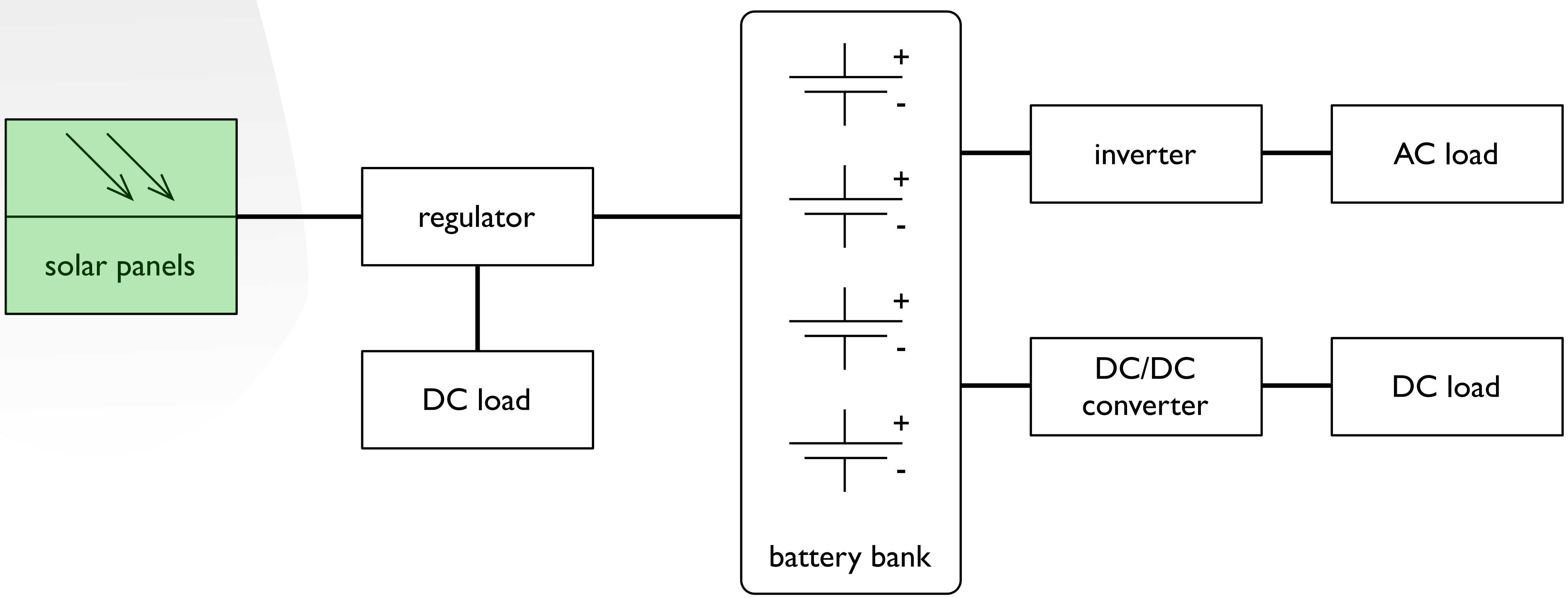
http://www.solar4power.com/solar-power-global-maps.html

http://www.synergyenviron.com/resources/solar_insolation_tool.asp

http://eosweb.larc.nasa.gov

Solar panels

The most obvious component of a photovoltaic system are the ***solar panels***.



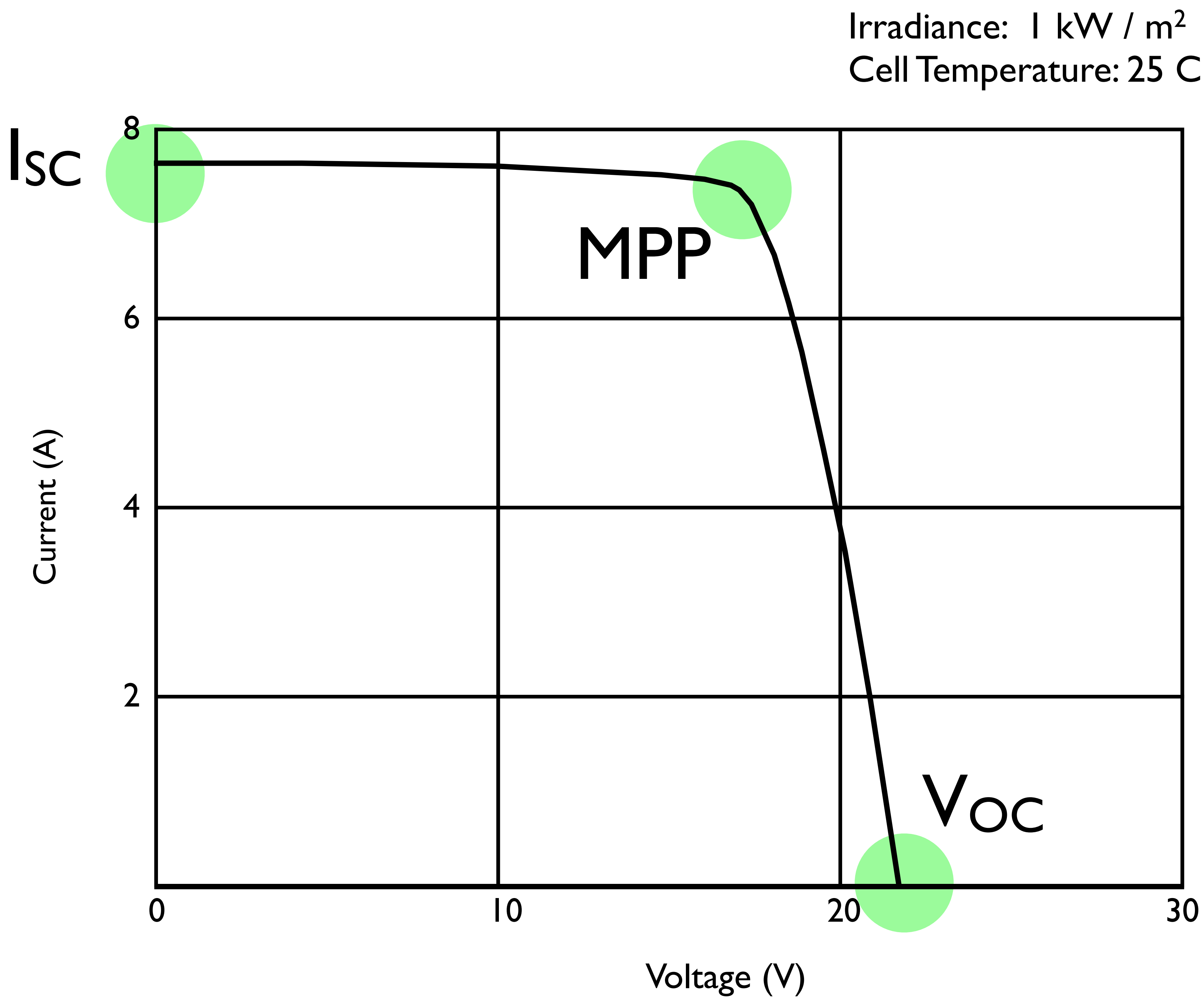
Solar panels

A solar panel is made of many solar **cells**

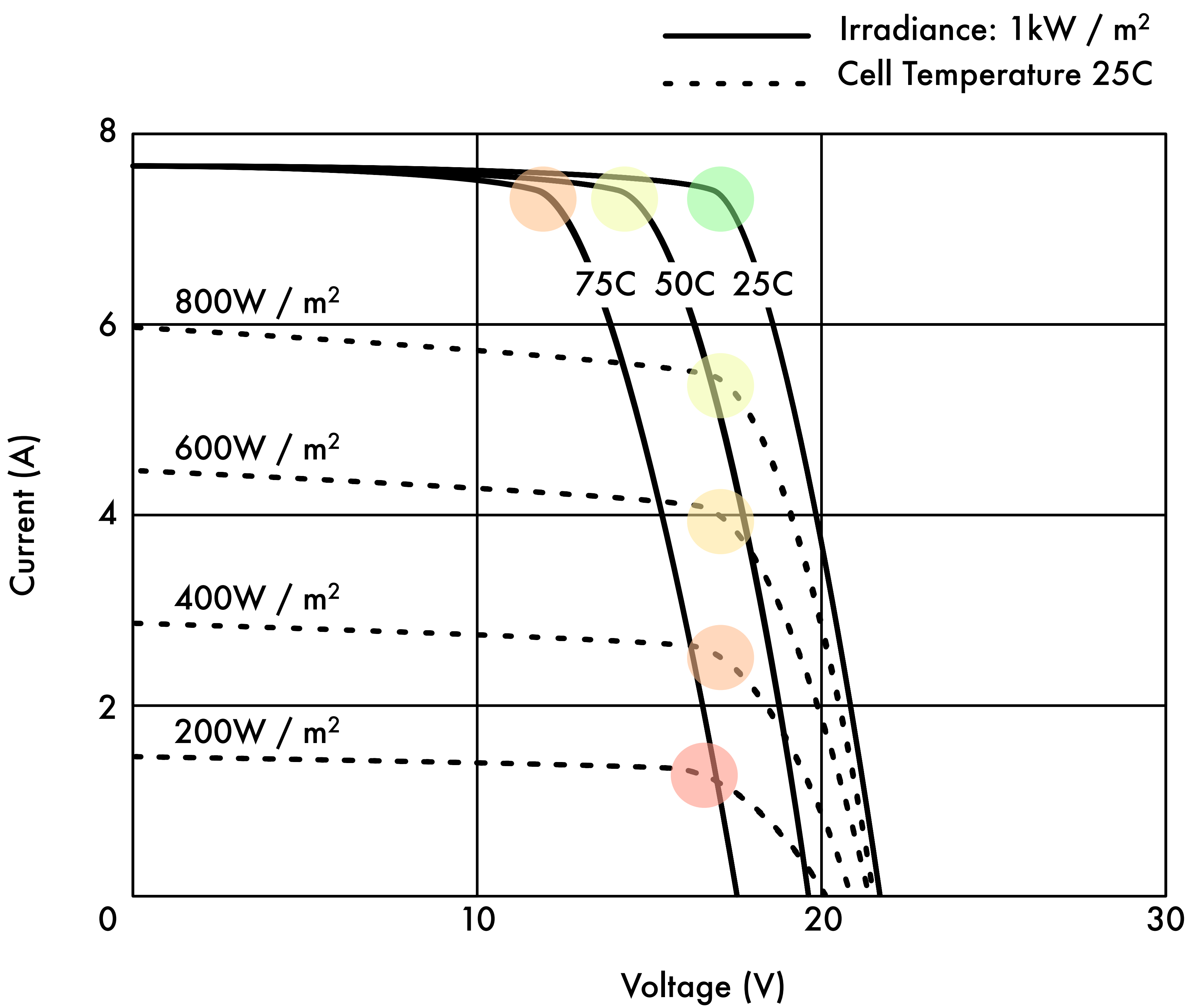
There are many types of solar panel:

- **Monocrystalline**: expensive, best efficiency
- **Polycrystalline**: cheaper, less efficient
- **Amorphous**: the cheapest, worst efficiency, short lifespan
- **Thin-film**: very expensive, flexible, low efficiency, special uses
- **CIGS**: Copper Indium Gallium Selenide

Solar panel IV curve



Solar panel IV curve for different amounts of irradiance and temperature

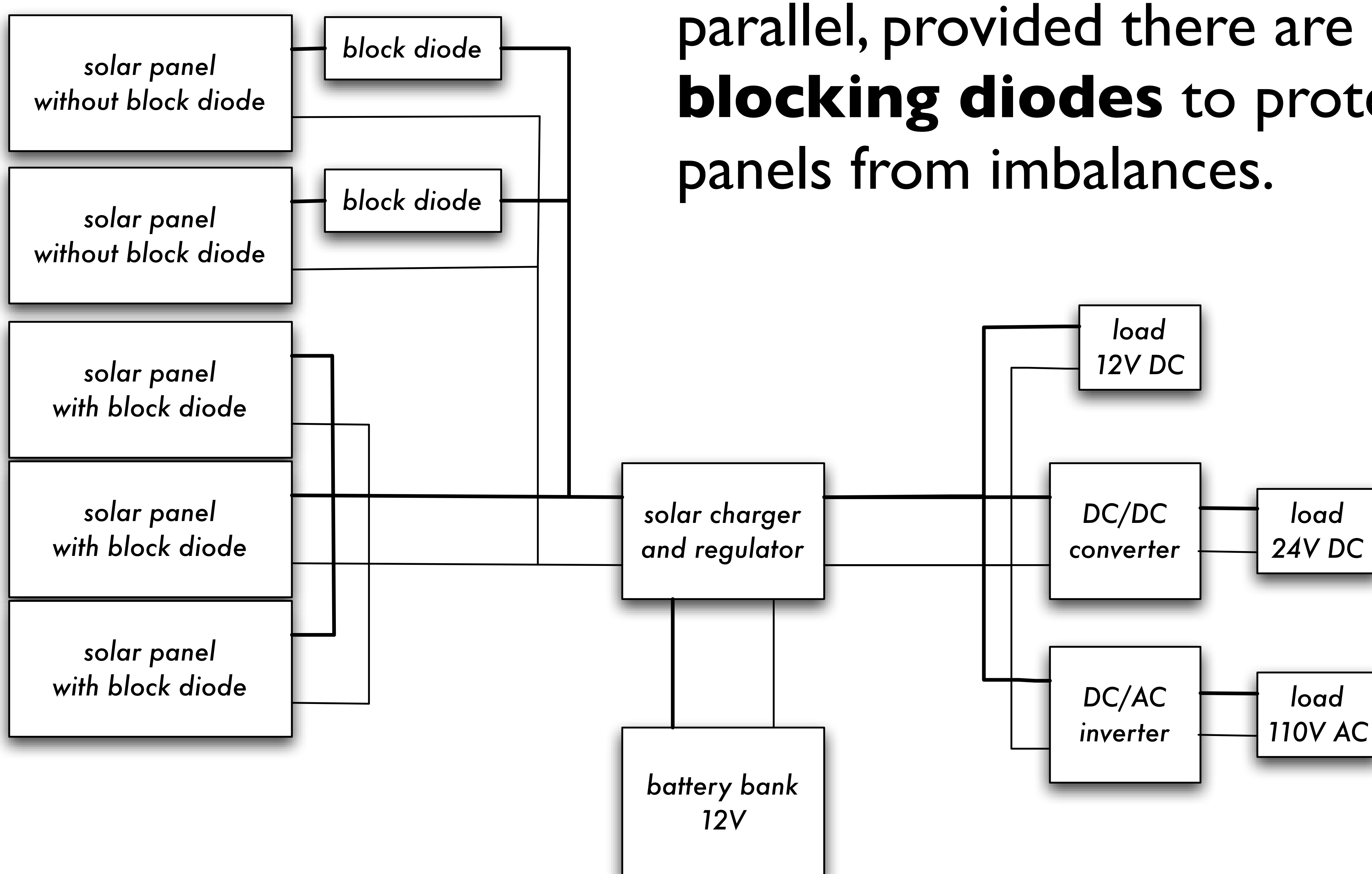


Optimizing panel performances

Optimal angle = Latitude + 5°

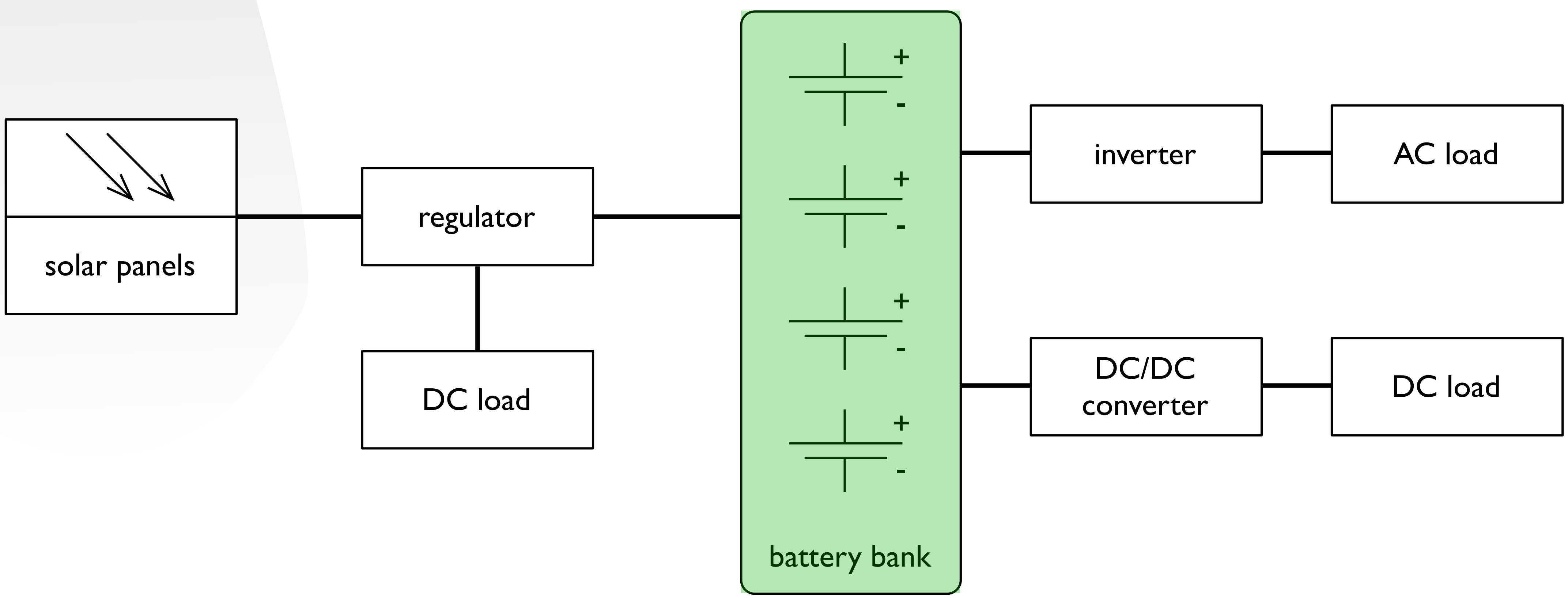
Photovoltaic system

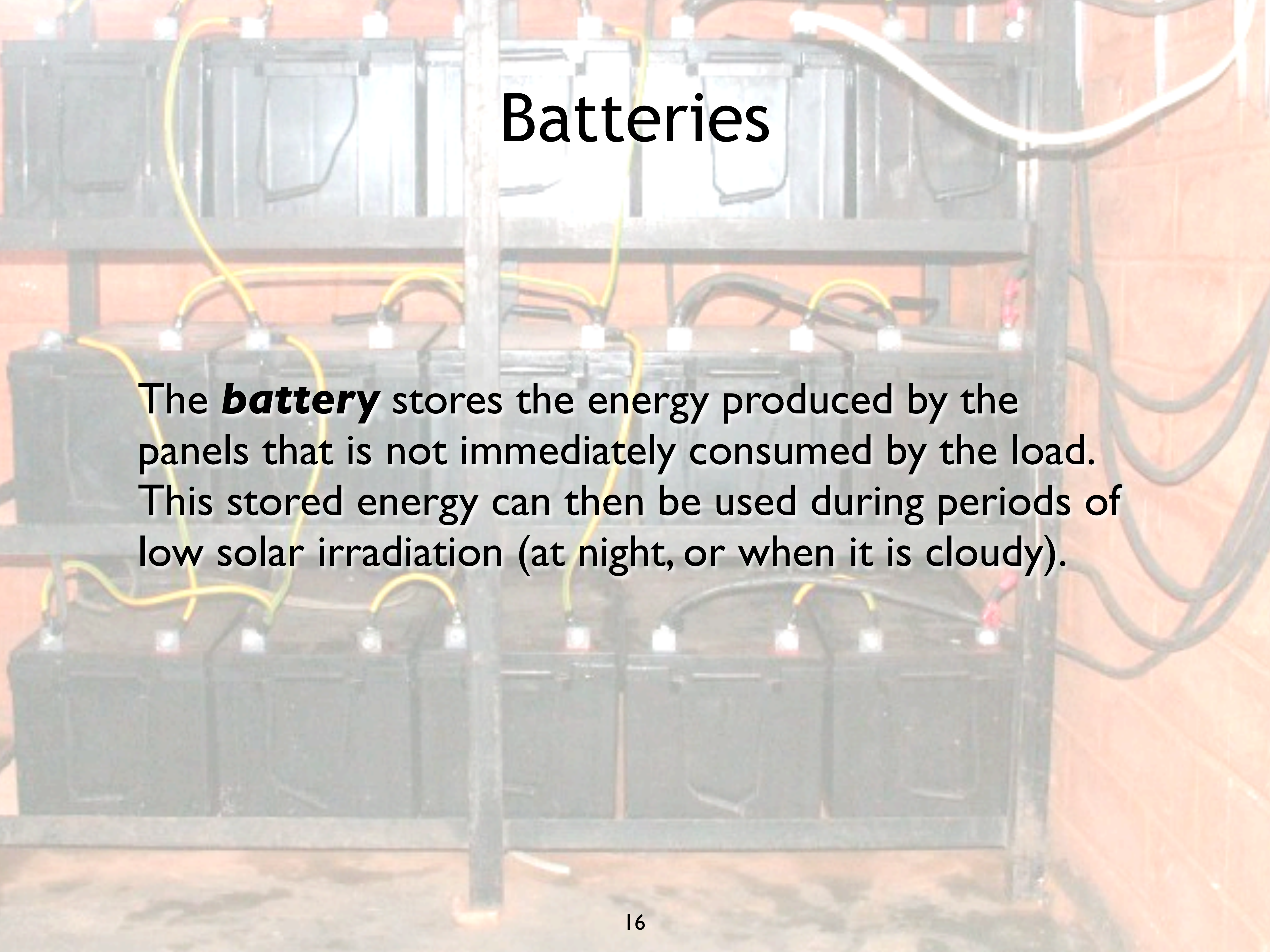
If more power is required, multiple solar panels may be joined in parallel, provided there are **blocking diodes** to protect the panels from imbalances.



Batteries

Batteries are at the heart of the photovoltaic system, and determine the operating voltage.





Batteries

The ***battery*** stores the energy produced by the panels that is not immediately consumed by the load. This stored energy can then be used during periods of low solar irradiation (at night, or when it is cloudy).

Batteries

The most common type of batteries used in solar applications are maintenance-free lead-acid batteries, also called **recombinant** or **VRLA** (valve regulated lead acid) batteries. They belong to the class of deep cycle or stationary batteries, often used for backup power in telephone exchanges.

They determine the ***operating voltage*** of your installation, for best efficiency all other devices should be designed to work at the same voltage of the batteries.

Operating voltage

Most autonomous solar systems work at 12 or 24 volts. Preferably, a wireless device that runs on DC should be used, operating at the 12 volts that most lead acid batteries provide.

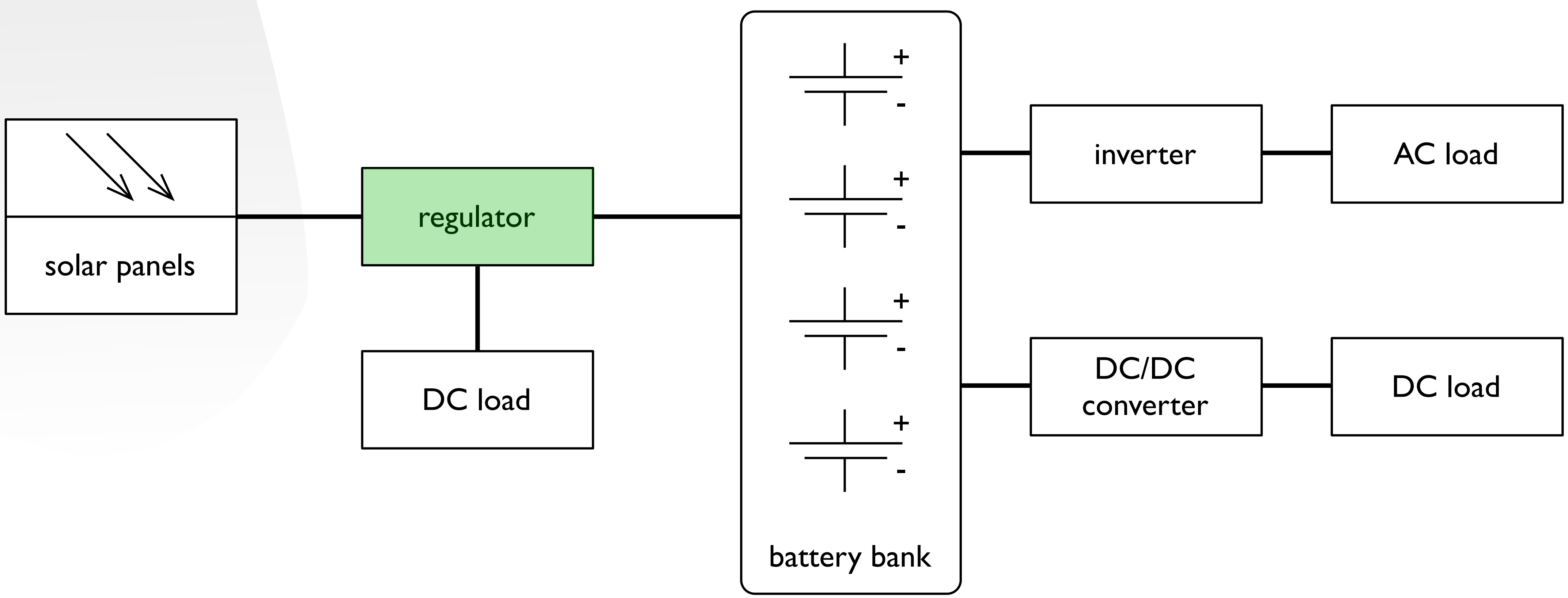
A router or access point that accepts 8-20 volts DC is perfect. Most cheap access points have a switched mode voltage regulator inside and will work through a wide voltage range without modification or becoming hot (even if the device was shipped with a 5 or 12 Volt power supply).

Designing a battery bank

- The size of your battery bank will depend upon:
  - the storage capacity required
  - the maximum discharge rate
  - the storage temperature of the batteries (lead-acid only).
- The storage capacity of a battery (amount of electrical energy it can hold) is usually expressed in amp-hours (Ah).
- A battery bank in a PV system should have sufficient capacity to supply needed power during the longest expected period of cloudy weather.

Regulator

The ***regulator*** is the interface between the solar panels and the battery, and can often provide power for moderate DC loads.



Regulator

PROSTAR
PROSTAR-30
SOLAR CHARGE CONTROLLER
VERSION: PS-30
MORNINGSTAR
corporation
CHARGING
TEMP. SENSOR
BATTERY STATUS
BLINK: LOW
ON: LVD
BATTERY TYPE
1 – GEL
2 – SEALED
3 – FLOODED
SOLAR
BATTERY
SENSE
LOAD

Monitoring the state of charge

There are two special states of charge that can occur during the cyclic charge and discharge of the battery. They should both be avoided in order to preserve the useful life of the battery.

- ***Overcharge*** takes place when the battery arrives at the limit of its capacity. If energy is applied to a battery beyond its point of maximum charge, the electrolyte begins to break down. This produces bubbles of oxygen and hydrogen, a loss of water, oxidation on the positive electrode, and in extreme cases, a danger of explosion.

Monitoring the state of charge

- ***Overdischarge*** occurs when there is a load demand on a discharged battery. Discharging beyond the battery's limit will result in deterioration of the battery. When the battery drops below the voltage that corresponds to a 50% discharge, the regulator prevents any more energy from being extracted from the battery.
- The proper values to prevent overcharging and overdischarging should be programmed into your charge controller to match the requirements of your battery system.

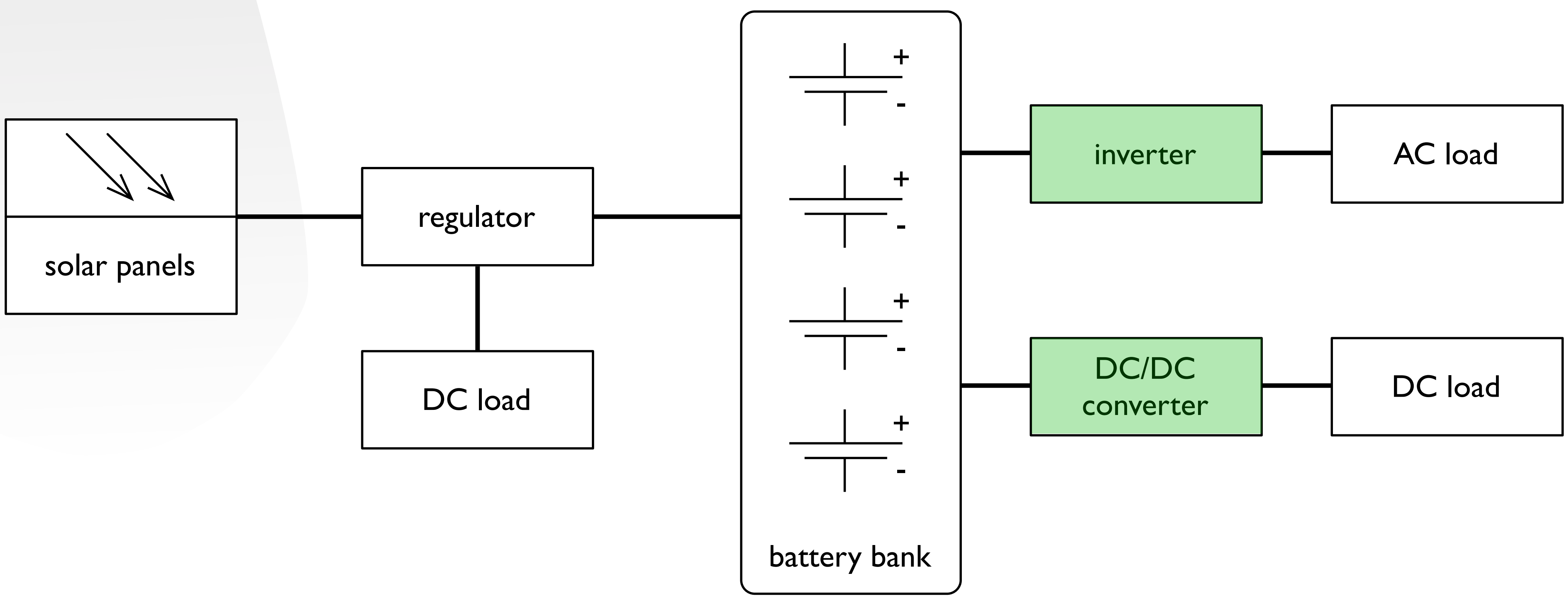
Maximizing battery life

Lead acid batteries degrade quickly if they are discharged completely. A battery from a truck will lose 50% of its design capacity within 50 -100 cycles if it is fully charged and discharged during each cycle.

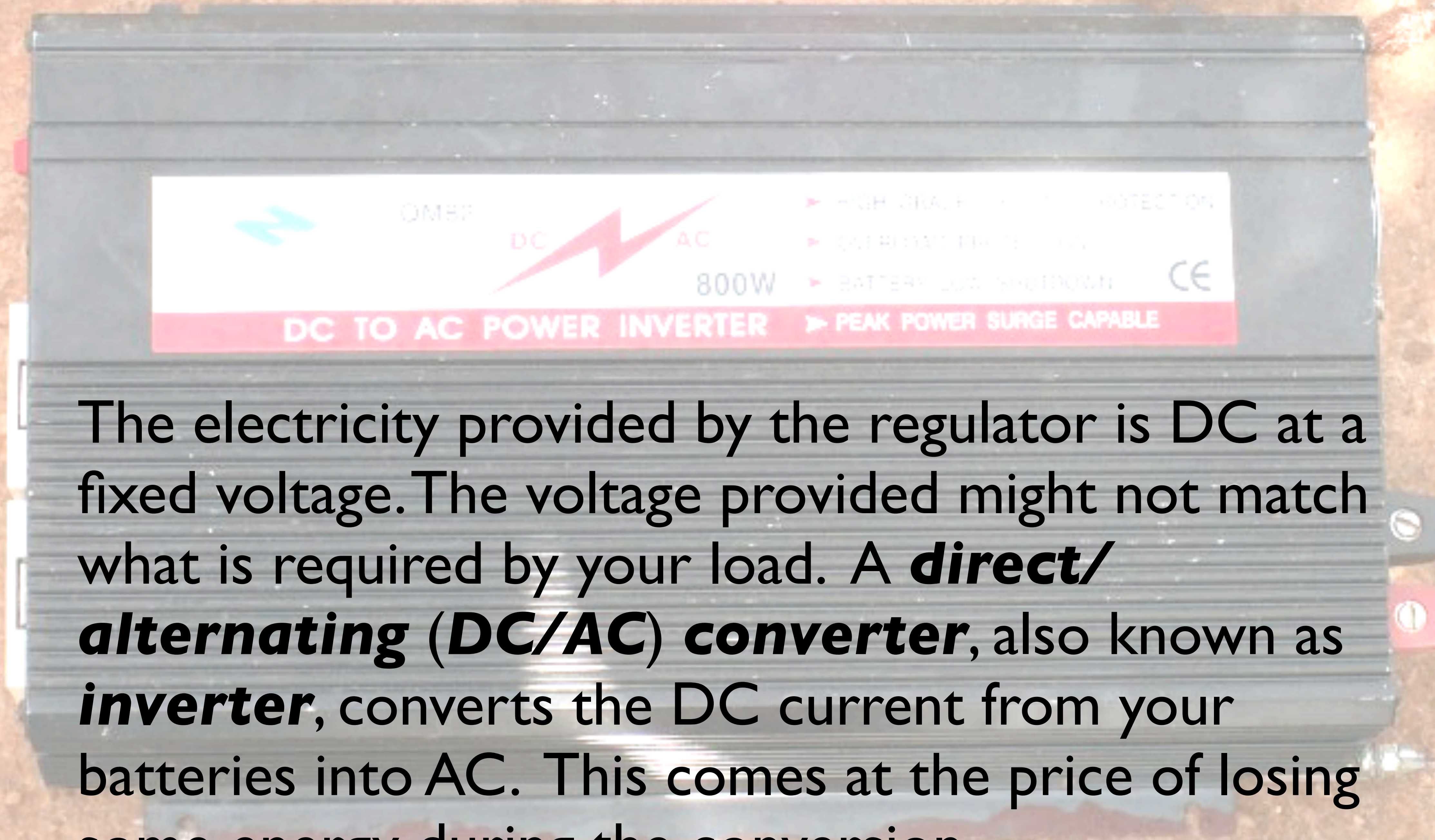
Never discharge a 12 Volt lead acid battery below 11.6 volts, or it will forfeit a huge amount of storage capacity. In cyclic use it is not advisable to discharge a truck battery below 70%. Keeping the charge to 80% or more will significantly increase the battery’s useful lifespan. For example, a 170 Ah truck battery has a usable capacity of only 34 to 51 Ah.

Voltage converters

An ***inverter*** turns DC into AC, usually at 110V or 220V. A ***DC/DC converter*** changes the input DC voltage into a desired value.

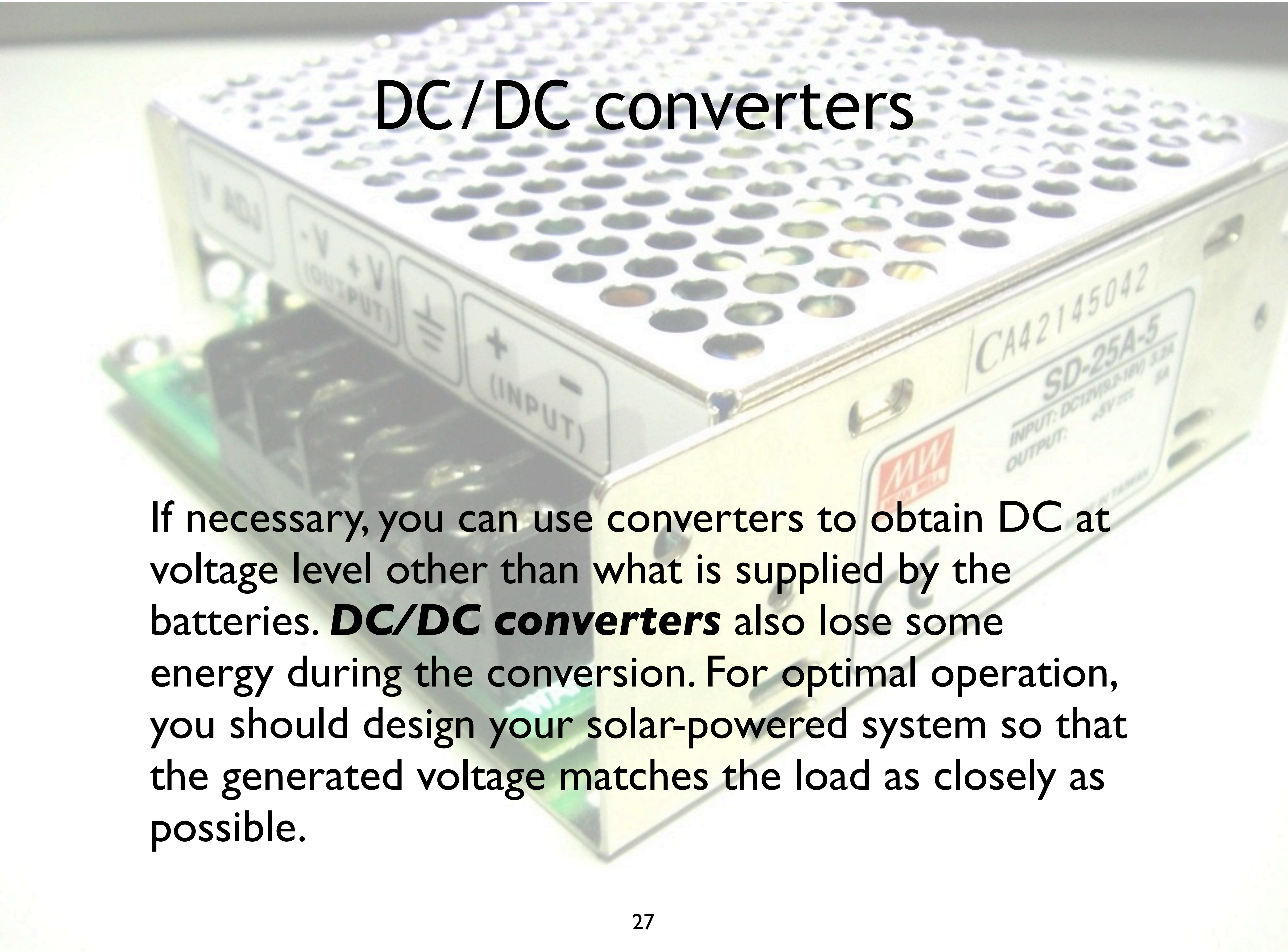


AC/DC inverters

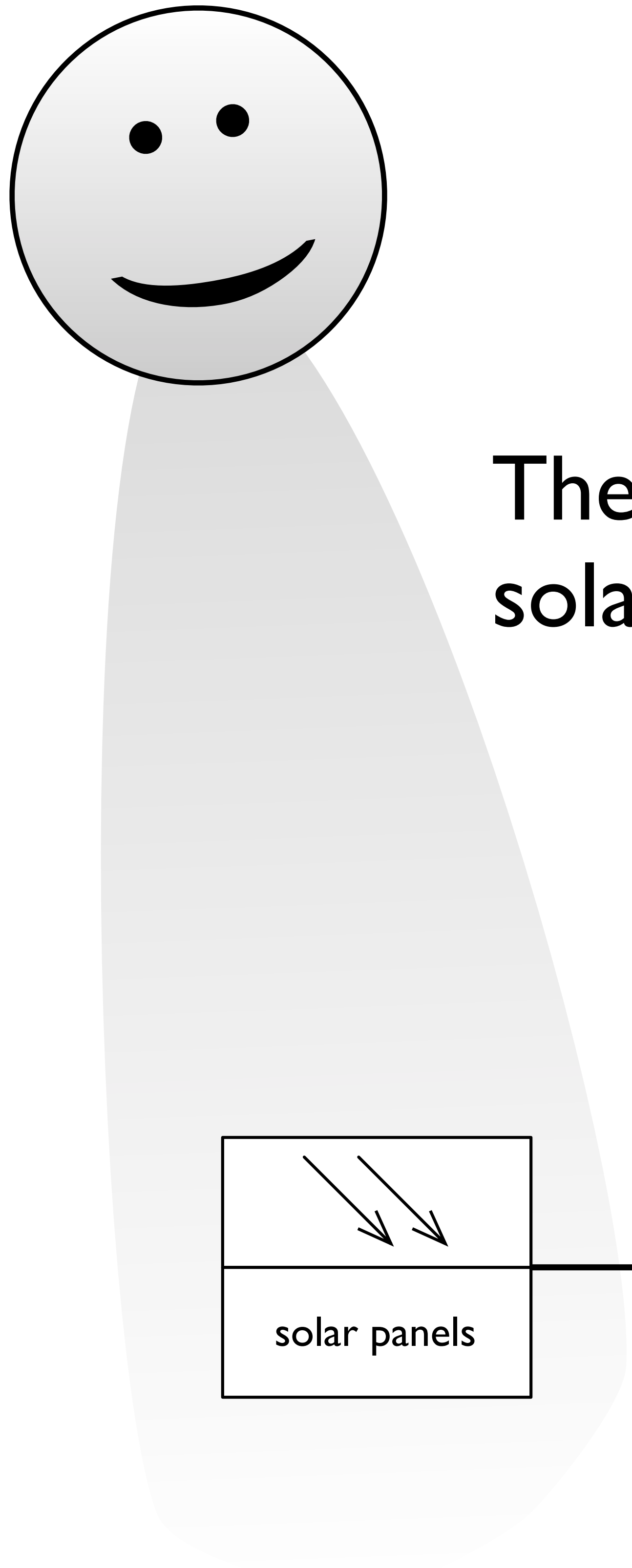


The electricity provided by the regulator is DC at a fixed voltage. The voltage provided might not match what is required by your load. A ***direct/alternating*** (***DC/AC***) ***converter***, also known as ***inverter***, converts the DC current from your batteries into AC. This comes at the price of losing some energy during the conversion.

DC/DC converters

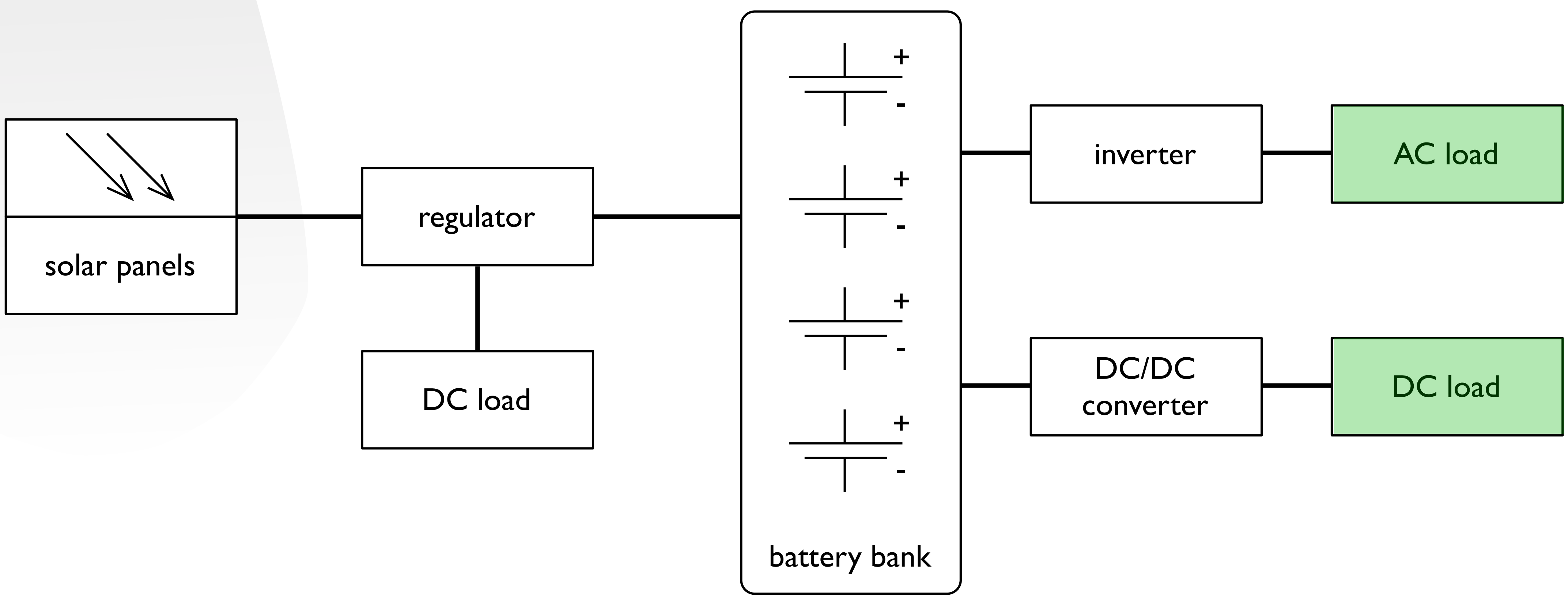


If necessary, you can use converters to obtain DC at voltage level other than what is supplied by the batteries. ***DC/DC converters*** also lose some energy during the conversion. For optimal operation, you should design your solar-powered system so that the generated voltage matches the load as closely as possible.



The load

The ***load*** is the work that is actually done by the solar energy system.



The Load

The ***load*** is the equipment that consumes the power generated by your energy system.

The load is expressed in watts, which are

$$\text{watts} = \text{volts} \times \text{amperes}$$

If the voltage is already defined, the load can be sometimes given in amperes.

Power consumption

The easiest way to measure how much power your load requires is to use a laboratory power supply that features a voltage and ampere meter. You can tune the voltage at the laboratory power supply and see how much current the device draws at different voltages.

If a laboratory power supply is not available, measurement can be performed by using the supply shipped with the device. Interrupt one cable that goes to the DC input of your device and insert an ***ampere-meter*** (***ammeter***).

Power consumption

The amount of power consumed can be calculated with this formula:

$$P = V \times I$$

P is the power in Watts, ***V*** is voltage in Volts, and ***I*** is the current in Amperes.

For example:

$$6 \text{ Watts} = 12 \text{ Volts} \times 0.5 \text{ Ampere}$$

If this device is operating for an hour it will consume 6 Watt-hours (Wh), or 0.5 Ampere-hours (Ah) at 12V. Thus the device will draw 144 Wh or 12 Ah per day.

Wind power

A ***wind generator*** is an option for an autonomous system on a hill or mountain.

The average wind speed over the year should be at least 3 to 4 meters per second.

Hint: locate the generator as high as possible

Wind power

The maximum available wind power is given by:

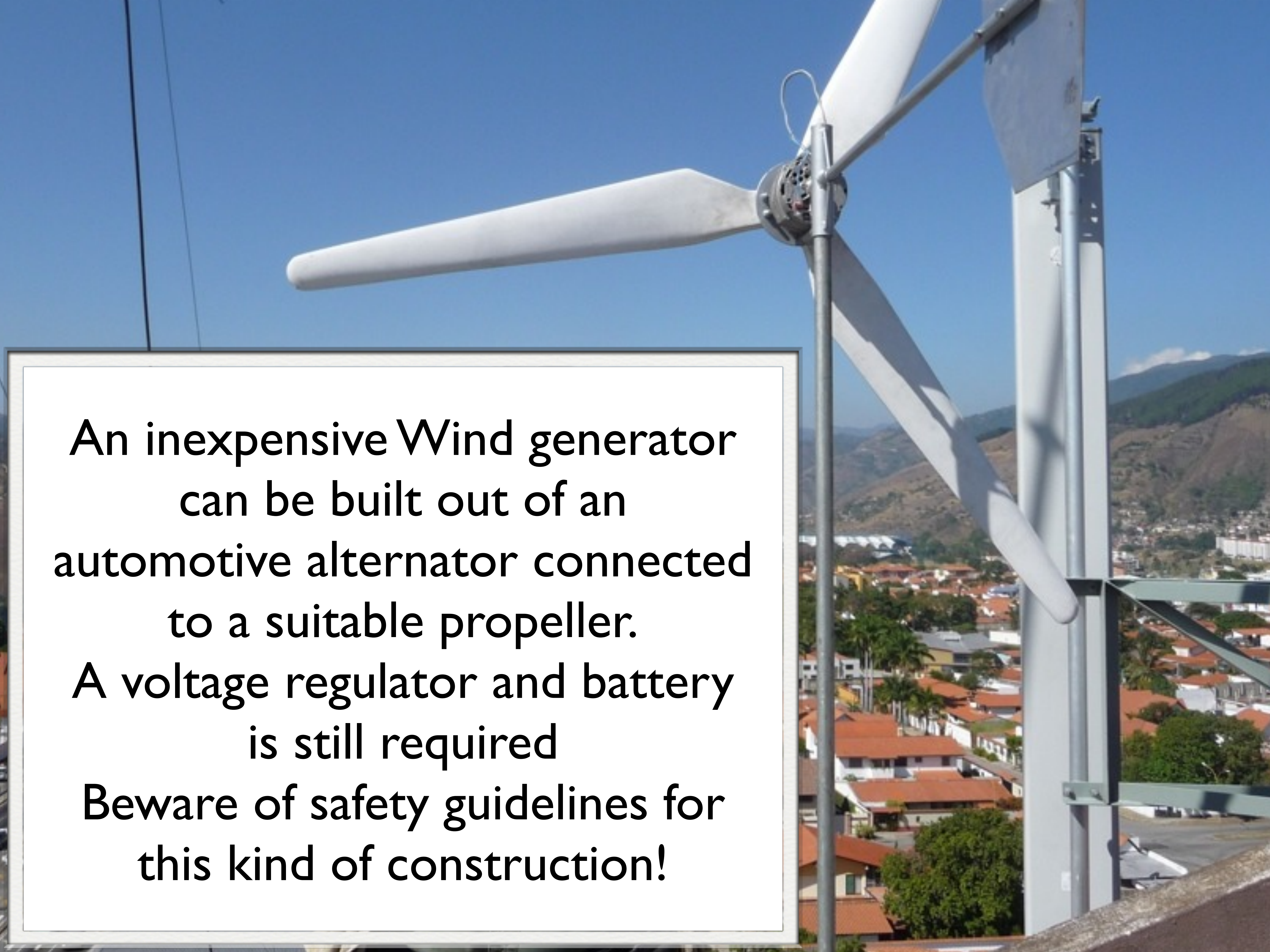
$$P = 0.5 * 1.225 * v^3 \ [W/m^2]$$

where v is in m/s, and assuming air density of 1.225 kg/m^3. This corresponds to dry air at standard atmospheric pressure at sea level and 15 Celsius.

The efficiency of wind generators range between 20 and 40%

Wind generators

- Integrated electronics: voltage regulation, peak power tracking, and electronic braking
- Carbon fiber blades are extremely light and strong.
- Wind generators can be used in conjunction with solar panels to gather power, even at night.



An inexpensive Wind generator can be built out of an automotive alternator connected to a suitable propeller.

A voltage regulator and battery is still required

Beware of safety guidelines for this kind of construction!

Conclusions

- Solar or wind power are viable means to provide energy where grid power is unavailable
- Batteries for energy storage and proper charge regulators are also required
- The latter may also be useful in instances where the grid power is available but not reliable
- Photovoltaic systems are expensive, so it pays to do a careful estimation of the real minimum requirements
- Avoid using power inverters

Thank you for your attention

For more details about the topics presented in this lecture, please see the book ***Wireless Networking in the Developing World***, available as free download in many languages at:

http://wndw.net/