International approach

to SMART ENERGY solutions

Workshop: Primary school

Experiments on energy generation with solar cells

Stredná odborná škola polytechnická Ul. SNP2 Zlaté Moravce

Učíme pre život!

vti tielt

Erasmus+

epos

1 Description

In the theoretical part follow topics will be explained:

- Sun
- photovoltaics
- energy generation with sun
- test criteria, production of solar cells
- The different options, such as island systems and Grid feed-in

The experimental part includes the following areas:

- Different light sources
- Series connection / Parallel connection of solar cells
- Partial shading of solar cells in a compound structure light filters and cloudiness conditions
- Advantages of tracking systems
- Roof incline and influence on the performance

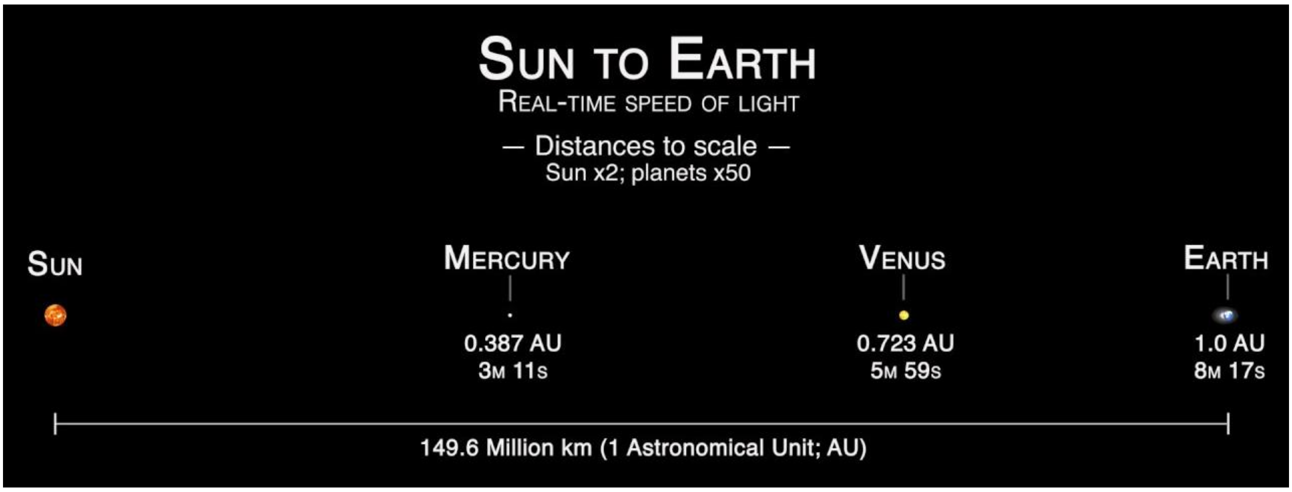
2 Equipment

- 2 x Solar cells mono SM330 0.5 V / 330 mA
- 1 x Solar motor RF300
- 4 x Cable with kroko clamps
- 5 x Coloured foils
- 5 x Shading cover
- 1 x Wooden parts set: Motor mounting with spiral disc
- 1 x Wooden parts set: Solar cell mounting with engraving
- 1 x Wood glue
- Digital meter

3 Theoretical part

3.1 Sun

The sun has 333000 times the mass of the earth and the largest energy reservoir of our solar system. With a diameter of 1,392 million kilometres it is more than one hundred times as large as the earth.



The average distance from the earth to the sun is 150 million kilometres. Every day, rays of the sun reach us after a travel time of 8 minutes. The light travels a distance of 299792.5 km per second.

Technically speaking, the sun is huge gas ball.

This is how we can imagine how hot the sun actually is:

50, 60 degrees Celsius:	The desert during the day.
90-100 degrees Celsius:	The temperature in a sauna
100 degrees Celsius:	Water evaporates.
3000 degrees Celsius:	Metal melts within seconds.
5700 degrees Celsius:	The surface of the sun
15000000 degrees Celsius:	The temperature of the sun.

The temperatures and also the pressure on the inside of the sun are so high that there are atomic reactions. Due to these atomic reactions 4 million tons of matter are burned every second whereas every gramme of burnt matter creates 25 000 000 kWh of energy.

3.2 The principle of photovoltaics

The conversion of light into electrical energy is called photovoltaics. In Greek language "phos = light" and "Volt - unit of electrical current".

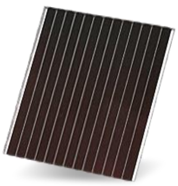
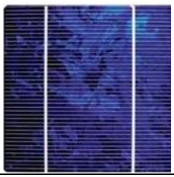
3.2.1 The level of efficiency

But what exactly is the level of efficiency?

The level of efficiency determines the ratio of entered energy and gained energy in percent. Example: If 1000 watts input power create an output power of 100 watts, the level of efficiency is 10%.

3.2.2 The different solar cells

The three solar cells that are currently in use:

Cell types	Material	Level of efficiency
Amorph cell  	Steamed-on silicium layer	up to 7%
Polycrystalline cell 	silicium discs	up to 16%
Monocrystalline cell 	silicium discs	up to 20%

Regarding the price, the amorph solar cell is by far the lowest priced. However, it also loses a significant amount of performance after just a few years. Poly and monocrystalline solar cells on the contrary have the same performance also after many years (up to 25 years). These cells are slightly more expensive, but more cost effective due to their high longevity.

3.3 Material

The material that solar cells are made of is quartz sand. It is cleaned of contamination by a special procedure and then processed to a silicium block. Depending on the type of the cell, different procedures are necessary to do this.

The Czochralski crystal-pulling process is applied for **monocrystalline cells**. A silicium crystal is dipped into the hot, liquid silicium. The liquid silicium joins with the dipped-in silicium crystal, while it is slowly drawn back out of the pot. This creates silicium sticks with a length of over 1 metre.

On **polycrystalline cells** the hot silicium is poured into a mould and cooled off gradually. This method also creates silicium sticks. Now these sticks that were created in both methods are cut into paper-thin layers (< 0,5 mm). Every disc is smoothed by cauterising and grinding.

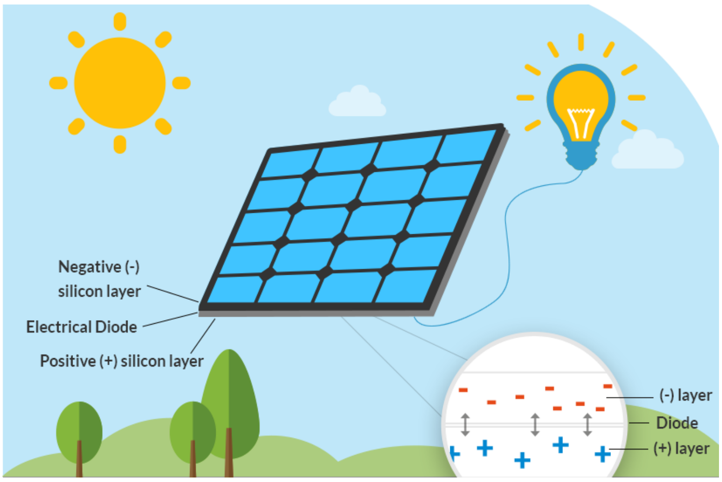
Subsequently both sides are contaminated purposefully with different foreign atoms. This is called "doping". Doping charges one side positively, and one side negatively, which later enables electric power to flow upon incidence of light.

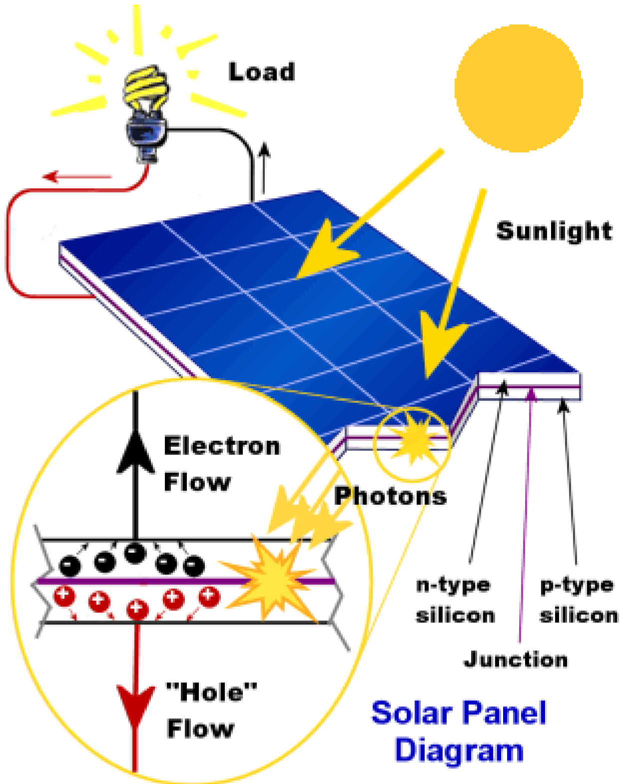
The backside of the solar cell is coated with a very thin aluminium layer. This aluminium layer serves as positive pole. The front side is also coated with aluminium, however not all the way, but only to form narrow conductor paths so that light can continue to reach the silicium.

Ultimately, a solder tail is created on the conductor paths that provides the second connection, the negative pole. Modern solar cells are 6" large.

Construction of a solar cell:

A solar cell produces direct current voltage. Depending on the quality of the cell this current may lie between 0.5 and 0.65 volt. The size of the solar cell determines the power



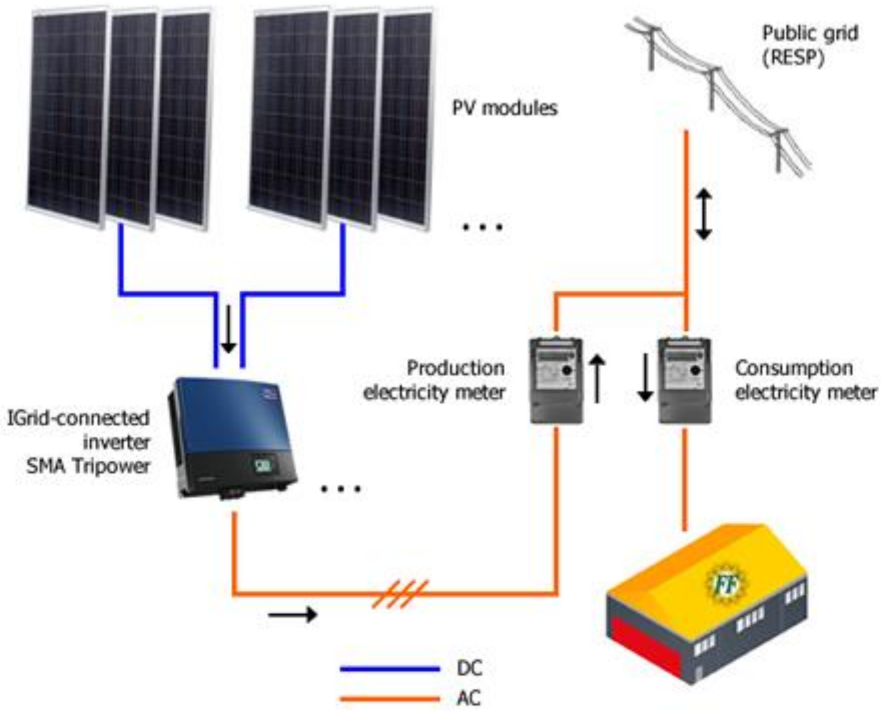


3.4 Application examples of photovoltaics

Mainly solar modules are currently used for power generation.

3.4.1 Feed-in into the public power grid

Parallel connections serve the purpose of feeding power generated by photovoltaics into the public power grid. Such a parallel connection consists of solar modules, a grid feeder, a main switch and if applicable a recording system for the evaluation of the feed-in data.

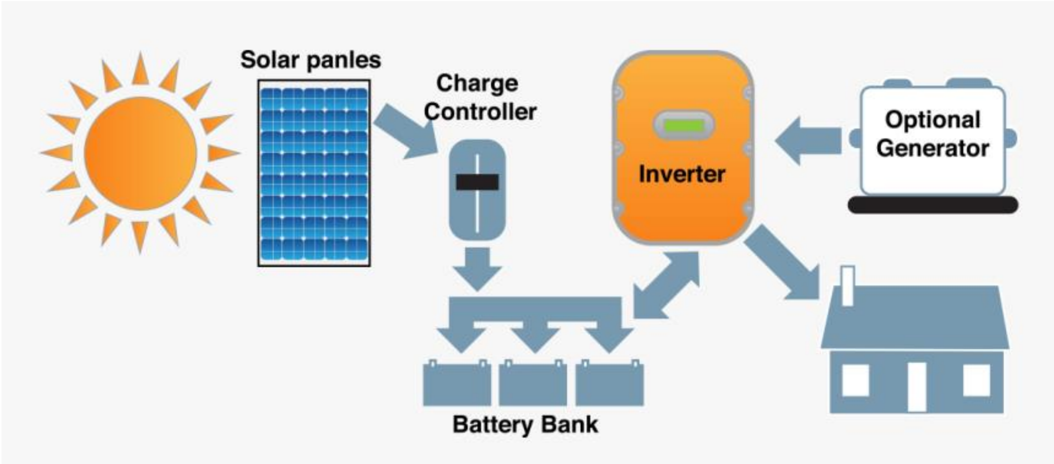


The inverter for feed-in converts the direct current into alternating current and feeds it into the public power grid.

If not enough energy is available through the solar unit, for example during nighttime or bad weather, the operator draws power out of the public power grid.

3.4.2 Power supply independent from the public power grid (off the grid)

Island units are used for places where there is no public power grid available. As it is the case for example in RV´s, boats, or alpine cabins. In order to operate such an island unit one requires solar modules, charger regulators and batteries, and of course also consumers like lamps, radios or the like.



- **The solar module**

  The solar module usually consists of 36 single solar cells that are connected in parallel operation. The current strength of the cell is decisive for the total power.

- **The charge regulator**

  The charge regulator prevents the battery of becoming overcharged by the solar module, as this is very damaging to the battery. If the battery is loaded, the charge regulator separates the solar module from the battery. Good charge regulators also possess a deep discharge protection. The deep discharge protection ensures that the consumers only discharge the battery up to a certain preset voltage.

  After that, the charge regulator automatically turns off the consumers. If the battery is now charged again over the solar module, the consumers are turned on again. In the usage of charge regulators without deep discharge protection deep discharge can happen repeatedly. This significantly reduces the lifetime of the battery.

- **The battery**

  The battery only serves as reservoir for the power that is created by the solar module. This way energy can be saved during daylight and can be obtained during the day or night.

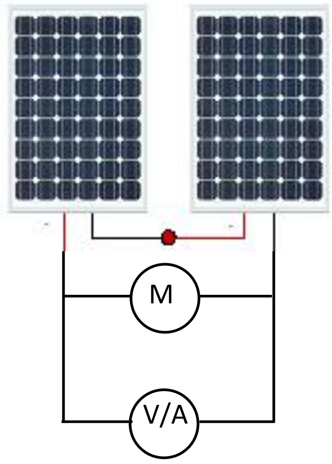
- **The inverter**

  The inverter converts the battery voltage of 12 volt direct current into 230V-devices can be connected to the solar unit like for example TV, lamps, radio, etc.

4 Experiments

4.1 LIGHT

Schematic:



M: motor

V/A: measurement with a multimeter

4.1.1 Influence of different light sources

Different sources of light produce different performances in solar cells. The best source of light for photovoltaics is sunlight.

The different sources of light that we want to use should have the same distance (approx. 30 cm) to the solar cells.

Source of light	Lightbulb	Neon pipe	Halogen lamp	Sunlight
Voltage in V				
Power in mA				
Performance in W (P = U.I)				
Motor turns (F/M/S/N)				

F: fast
M: medium speed
S: slow
N: now rotation

What is your conclusion?

4.1.2 Influence of light filters

Conventional light filters in solar technology are mainly different conditions of cloudiness. The cloudiness range reaches from “clear sky” to light, medium, up to strong cloudiness.

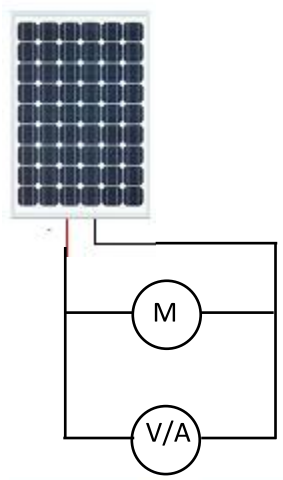
Different light spectrums are lost through the filtering of the light. Depending on the foil colour, different light spectrums are filtered out. Therefore the solar cell releases a respectively different performance.

Color of the foil	without foil	transparent	yellow	green	red	blue
Voltage in V						
Power in mA						
Performance in W (P = U.I)						
Motor turns (F/M/S/N)						

What is your conclusion?

4.2 Difference between serial and parallel connections

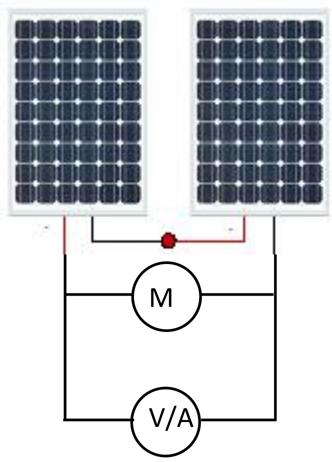
Schematics: One cell



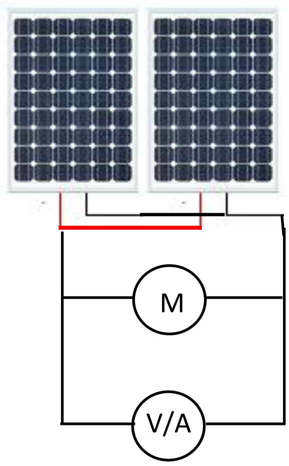
M: motor

V/A: measurement with a multimeter

2 serial cells:2



parallel cells:



- **Serial:**

In order to increase the voltage of a solar unit, single solar cells must be connected in series. This is typical for example for standard modules, as they consists of 36 - 40 cells that are connected in series.

- **Parallel:**

In order to increase the power of a solar module, single solar cells must be connect in parallel. To prove this, we create the following connection.

Only solar cells of the same type may be connected in parallel.

Connections	One cell	2 cells serial	2 cells parallel
Voltage in V			
Power in mA			
Performance in W (P = U.I)			
Motor turns (F/M/S/N)			

What is your conclusion?

4.3 Cell shading

4.3.1 Partial cell shading

Same schematic as serial (page 10)

Partial shading leads to significant performance loss of solar cells. We now want to determine the ratio of the percentual shading to the decrease in performance of the solar cells. The more a solar cell is shaded, the less power it produces.

Shading %	0	25	50	75	100
Voltage in V					
Power in mA					
Performance in W (P = U.I)					
Motor turns (F/M/S/N)					

What is your conclusion?

4.3.2 Cell shading because of total failure

- **Same schematic as serial (page 10)**

Cell shading in series connection lead to a total performance failure of the system as the shaded solar cell reaches a high inner resistance and thus significantly reduced the power flow.

If a cell is shaded in series connection, the total performance drops to zero. This is dangerous especially for full modules, as these usually possess 36 solar cells connected in series.

Shaded solar cell	No solar cell	Left solar cel	Right solar cell
Voltage in V			
Power in mA			
Performance in W (P = U.I)			
Motor turns (F/M/S/N)			

What is your conclusion?

- **Same schematic as parallel (page 10)**

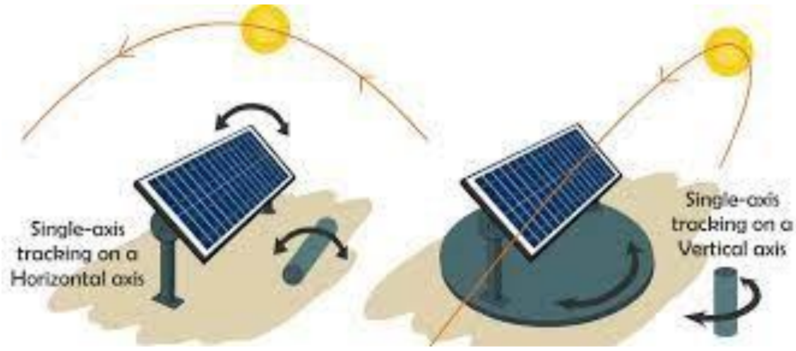
Partial shading in parallel connection of solar cells lead to a loss of performance, but not to a total performance failure of the system. We will now prove this with an experiment.

If a solar cell is shaded in parallel connection, the total performance is reduced by this solar cell performance. Only if all solar cells are shaded does the total performance go back to zero.

Shaded solar cell	No solar cell	Left solar cel	Right solar cell
Voltage in V			
Power in mA			
Performance in W (P = U.I)			
Motor turns (F/M/S/N)			

What is your conclusion?

5 Tracking



5.1 Horizontal tracking

This experiment shows that different roof inclines produce different performances of the solar cells. The angle “roof incline” can be read on the side of the solar cell mounting. Important: The lamp light must come directly from the front!

A solar module will have ideal performance if it is positioned in a 90 degree angle to the source of light (sun). if e.g. solar modules are adjusted to the horizontal position of the sun during wintertime, this produced higher exploitation and thus higher profit in parallel connections.

Angle to the light in %	90 vertical	60	45	30	0 horizontal
Voltage in V					
Power in mA					
Performance in W (P = U.I)					
Motor turns (F/M/S/N)					

What is your conclusion?

5.2 Vertical tracking

Is it profitable to track a solar unit vertically to the sun? And how is the ratio angle - performance?

An interesting experiment with a spectacular result.

If a solar unit tracks the sun, the total profit of the unit increases by up to 50%. The additional costs accruing due to the tracking are balanced within a short time with the additional profit.

Angle to the light in %	0	10	20	30	40
Voltage in V					
Power in mA					
Performance in W (P = U.I)					
Motor turns (F/M/S/N)					

What is your conclusion?