Photovoltaic plants – Energy to Infinity

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The aim of this paper is to discuss photovoltaic plants and the needs of energy in the near future. The functionality of photovoltaic cells, the photoelectric effect in solar cells and the production of solar panels is presented. The economy of solar plants is also mentioned. The fourth industrial revolution urgently needs new sources of energy.

Keywords: Photovoltaic, Internet of Things, IoT, Industry 4.0, Space-based solar power

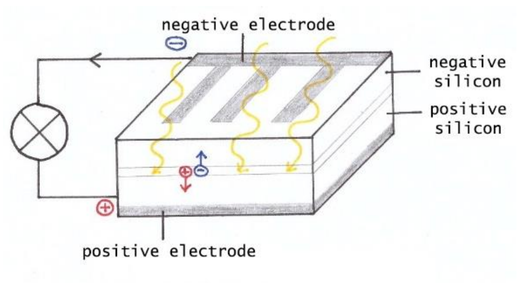
I. INTRODUCTION

We always need electricity. – The question which occurs is, if there isn't any oil, coal or other fossil fuels that we can burn how do we get the demanded energy? No laptop, industry robot or either no lighting will work anymore. Our resources on earth shrink, in contrast the expenditure of energy rises.
So humans have to find better sources of energy!
The solar panels on the Botball Game Desk brought up the idea to pick up this topic and discuss it in the paper. That opens the following question: How can we use them on the Mars or other planets? And do we have to take precautions if we use them on a foreign planet?
Furthermore, the "Fourth industrial revolution" demands sustainability, because energy is getting more and more important even in the industry. In our whole industry robots are needed to act automatically and energy is needed to run them.
Photovoltaic plants could be the answer to all these problems. The sun provides as much energy in one hour as the world consumes in one year.
In this paper it will be discussed how photovoltaic works, if it is economic and where we can use it.

II. TECHNICAL FUNCTIONALITY

Basically the photovoltaic principle is the conversion of energetic sunlight into electric energy with solar panels. The term "photovoltaic" is made up from "phos", Greek for light, and Volt, the SI-Unit for the voltage.

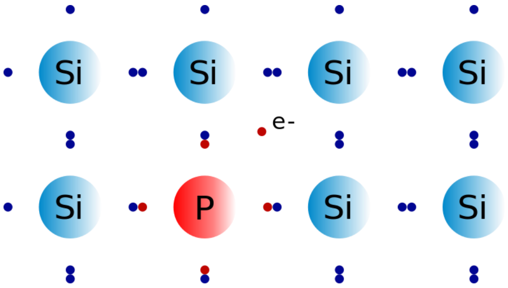
A. Structure of a Solar Cell



(1) Photovoltaic cell

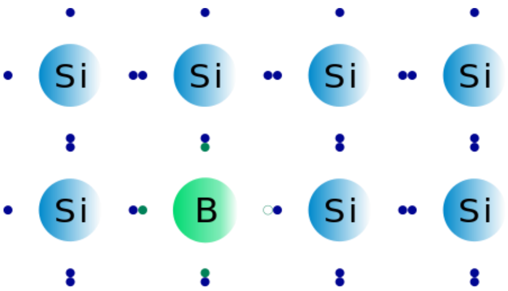
B. Photoelectric Effect

Solar panels are made of semiconductors. These are materials that release electrons fore example by light and heat, otherwise they can be used like isolators.
Most of the time silicon is used as semiconductor, because it is the second most frequent element on earth. Moreover, it is environmental friendly and the conductivity is three times higher, only by a temperature rise of 10 degrees. A solar cell consists of two oppositely charged semiconductors. The charging is reached by doping. In order to get an N-type silicon an element with one more valence electron can be used, e.g., phosphorous. N-type materials upturn the conductivity of a semiconductor by increasing the amount of available electrons.



(2) N-type silicon

By adding an element with one less valence electron (e.g., boron) to silicon a P-type silicon is formed. In that case the conductivity is increased by the number of holes.



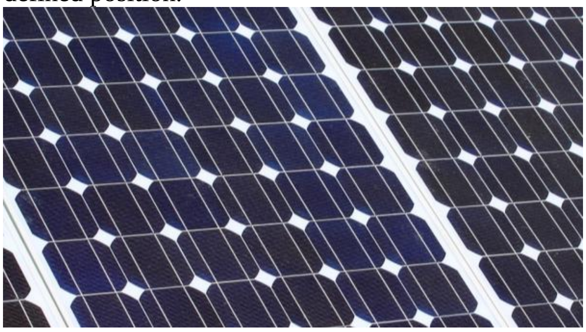
(3) P-type silicon

By joining a P-type with an N-type a junction is built.
If photons strike the cell, electrons in the lower semiconductor are emitted and move into the upper one, which has an excess of electrons. If a consumer is being added, the electrons can get into the upper semiconductor to compensate there the lack of electrons. This electron flow leads to direct current.

C. *Different Types of Solar Panels*

1) Monocrystalline Solar Panels

Monocrystalline solar panels are dark black and have no corners. Each module is made from a single silicon crystal. They are more expensive than the newer and cheaper polycrystalline. In laboratory they have an efficiency factor of about 24 percent. Under normal conditions they reach approximately 14 to 17 percent efficiency.
Monocrystalline solar panels are produced, by putting a bar of silicon through heat in the same direction over and over again. After that, the end can be cut off and the residue is pure silicon. The difference to polycrystalline solar panels is in the cooling process. A crystal ingot is dipped into melted silicon, then it is slowly put out. Monocrystalline silicon has an ordered crystal structure, with each atom ideally lying in the defined position.



(4) Monocrystalline cell

2) Polycrystalline Solar Panels

In contrast to monocrystalline panels the polycrystalline solar panels are light blue. The efficiency grade is a bit lower than for the monocrystalline solar panels. In laboratory they reach nearly 18 percent - under real conditions about 13 to 15 percent.
Techniques for the production of polycrystalline silicon are much easier and cheaper than for monocrystalline. It is only poured into a form and cooled down slowly. Then there are a lot of crystals with different size in the whole panel.

(5) Polycrystalline cell

D. *Rated output*

The rated output of solar plants is indicated in kWp (Kilowatt Peak). It specifies the power under Standard Test Conditions (STC).
These conditions are:

- 25° C temperature of the panels
- 1000 Watt/m² irradiance
- 1.5 AM air mass

In Austria these factors can hardly be reached. Only at noon on special days in summer there is such a high radiation energy, but then the temperature rises above 25 degrees and the output decreases.

III. ECONOMY

A. *Amortization*

1) Energetic Amortization

The energetic amortization time (EAT) is the period of time taken until the energy for construction, transport and disposal is compensated by the energy produced of the solar array. Depending on the type of solar panels, the EAT is between 1.5 and 4 years. Every month after this time helps to reduce CO_2 and protects our climate.

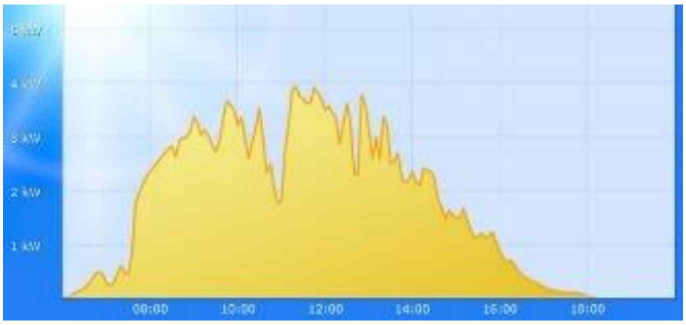
2) Economical Amortization

The economical amortization time is the time, until the money which is saved for electricity costs is as high as the costs of the solar array. This time is approximately 20 years.
A solar plant with 4.4 kWp that costs 13500€ supplies approximately 4.8 MWh energy a year. Electricity costs are about 16 cents per kWh. So the amortization time of this solar plant is about 17 years.

$$4800 \cdot 0.16 \cdot n = 13500$$
$$n = 17.6 \text{ years}$$

B. *Irregular Earnings*

A big problem of photovoltaic plants is that they only can supply electricity, while the sun is shining. The following graphics show the irregular earnings.



(6a) Graphics from a photovoltaic-user (sunny day)

(6b) Graphics from a photovoltaic-user (rainy-foggy day)

The 22nd March 2014 was a really sunny day. The solar plant supplied 22.92 kWh. But on the next day the 23rd March the weather was sunny and weather was foggy and rainy. Then there was only a gain of 3.11 kWh.
The earnings of photovoltaic plants and other renewable energies is depending on the weather. So the big challenge in future will be to develop efficient energy storages, to retain unnecessary electricity and to use it when required.

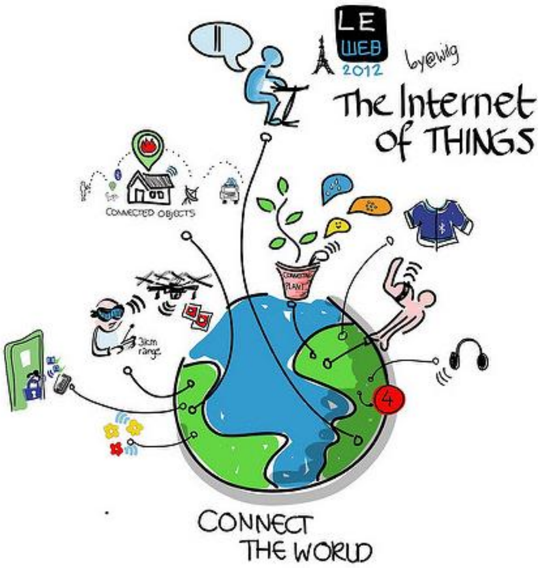
IV. Photovoltaic and Robots

A. Industry 4.0

Today's possibilities have blurred the border between the digital and physical worlds.
There are three main changes: Digitalization, Industrialization and Optimization. Digitalization means, that the production in all sectors is performed by digital technologies.
Industrialization stands for integrating new technologies in companies. Optimization means that already existing processes should be enhanced. Machines should configure and optimize automatically.

B. Internet of Things

The Internet of Things describes the network of electronic devices, vehicles and their sensors which are connected with the internet.
The illustration from "wilgengebroed" that is published on flickr.com shows the concept of the Internet of Things perfectly. Every device is fully integrated into a network and can communicate with others.



(7) The Internet of Things

C. Robots – the Future of Industry

Nowadays robots are used in nearly every economic sector (e.g., education, security, agriculture, tourism, healthcare and industry).
Advantages of industrial robots are that they are mostly cheaper, more agile and faster. The problem is that a system which consists only of robots is not flexible. In the future it will get vital to have a variable system. A collaborative robot will be the solution. The robot will work in direct cooperation with humans inside a defined workspace.

D. Energy Consumption

There are about 1.2 million industrial robots in use. All of them have to be supplied with electricity. Most of the energy is needed in the automobile industry. The painting and the body construction of cars are taken over by robots.
To get this energy in an economical friendly way, photovoltaic can be used.

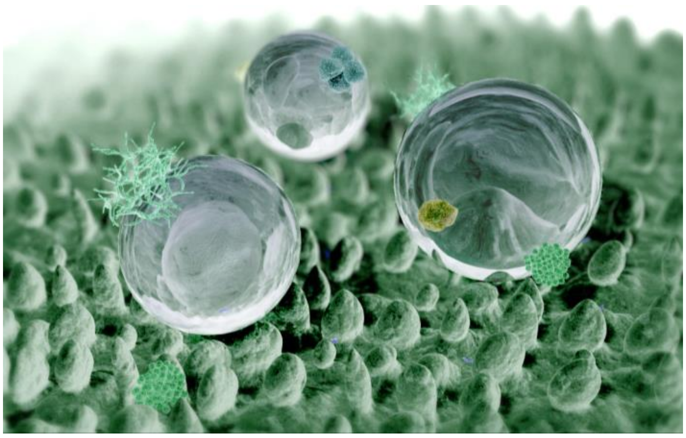
V. Solar plants in space

A. Space-based Solar Power (SBSP)

Space-based solar power is the concept of gaining energy by a satellite for use on earth. The idea is to collect solar energy and redirect it to earth by lasers, which are operating at eye-safe wavelengths and are beaming the energy to special receivers on Earth. A single satellite would be able to supply nearly 10 kW to the ground user with the laser power transmission system.
This principle would have lots of advantages. The satellites could collect the sun's energy also on cloudy days, because it would fly over them. The system could handle the peak times and provide electricity on demand.

B. Solar Plants on Mars

The Mars is a very dusty and dry planet. Photovoltaic panels do not work if they are covered with dust. 5 gram dust would reduce the gain of energy by 40 percent. So the developer of mars solar panels had to make precautions. They designed a film of special material on the solar panels. If the integrated sensors notice, that there is too much dust on it, the material get loaded electrically. Then there is an electric wave that moves the dust over the edge of the photovoltaic cell. In about two minutes 90 percent of the dust on the panel is removed.
Another possibility is the so called nanotechnology. On the surface of the solar panels there is a nanopattern. This method brings lots of advantages. The tiny structure leads to more efficiency. Significantly more sunlight can be converted into electricity. Moreover, it works with the Lotus-Effect (The lotus effect refers to self-cleaning properties that are a result of very high water repellence, as exhibited by the leaves of the lotus flower. https://en.wikipedia.org/wiki/Lotus_effect). The panels are dirt-repellent.
(8) Lotus Effect



VI. Conclusion

Photovoltaic energy is definitely the energy of our future. It is environmental friendly and it does not cause any risks in contrast to for example nuclear energy.
This technology can be used in households, companies or even on other planets. There are many different types and functionalities for the various areas of application.
Economy factors will get more and more important in future, so I hope that the amortization time will get shorter and the solar panels even more efficient.
Another vital part will be to compensate peak times of electricity usage. Either human will build really good storages, which can balance this, or they have to develop a concept for power on demand.

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