SOLAR ENERGETICS AND ITS ENVIRONMENTAL IMPACT

SOLÁRNÍ ENERGETIKA A JEJÍ VLIV NA ŽIVOTNÍ PROSTŘEDÍ

Vladimír LAPČÍK [1] , Marta LAPČÍKOVÁ [2]

[1] *prof. Ing. CSc., Institute of Environmental Engineering, Faculty of Mining and Geology, VSB - Technical University of Ostrava, tř. 17. listopadu 15, 708 33 Ostrava-Poruba, phone: (+420) 597 325 289, e-mail: vladimir.lapcik@vsb.cz*

[2] *Ing., Ministry of the Environment of the Czech Republic, Department of Public Administration IX, Čs. legií 5, CZ 702 00 Ostrava, phone: (+420) 595 136 476 e-mail: marta.lapcikova@mzp.cz*

Abstract

The article summarizes possibilities of utilization of solar energy in energetics. The article describes solar thermal power stations (inclusive of concentrating solar power stations), storage of solar energy by means of chemical energy (hydrogen) and its successive utilization in fuel cell, indirect conversion (thermo-electric conversion based on the so-called Seebeck´s phenomenon), and eventually direct (photovoltaic) conversion. The final part of the paper deals with questions of necessity of the environmental impact assessment process in the field of solar photovoltaic plants in the Czech Republic

Abstrakt

Příspěvek shrnuje možnosti využití sluneční energie v energetice. Popsány jsou sluneční tepelné elektrárny (termosolární elektrárny), uložení sluneční energie prostřednictvím chemické energie (vodík) a její následné využití v palivovém článku, nepřímá přeměna (termoelektrická přeměna založená na tzv. Seebeckově jevu) a konečně **p**římá (fotovoltaická) přeměna. Závěr příspěvku je věnován otázkám nutnosti posuzování vlivů fotovoltaických zařízení na životní prostředí v České republice.

Key words: solar energy, energetics

1 INTRODUCTION

Radiant flux corresponding to an output of 1,373 W falls on the area of 1 m^2 upright to sunrays outside the earth's atmosphere within a day. Its density is so-called **solar constant** (1.373 kW/m^2). The total power radiated by the Sun is $3.8.10^{26}$ W. However, only small portion falls on the surface of the Earth - about 180,000 TW ($1.8.10^{17}$ W). Thereby 34 % (approximately 60,000 TW) is reflected by the atmosphere and clouds (the so called Earth's albedo) back to the outer space and 66 % (approximately 120,000 TW) is absorbed both by the atmosphere (19 %) and Earth's surface (47 %). One per thousand of the energy absorbed by the Earth's surface (about 90 TW) is captured by photosynthesis [1]. From this energy captured by green plants and phytoplankton the whole biosphere lives. However, the energy is not the same at all points of the planet Earth.

Sunlight falls on the surface of the Czech Republic with an average intensity of 800 W/m^2 depending on location and climatic conditions. So the yearly incoming solar energy varies from 1,000 ÷ 1,250 kWh/m^2 (an average for CR is 1,081 kWh/m^2) [2].

Generating electricity directly from sunlight is the cleanest and most efficient way of its production.

2 SOLAR THERMAL POWER PLANTS (THERMOSOLAR)

In a solar thermal power plant sunlight is converted into electricity on a large scale. In principle this is a thermal plant obtaining the needful heat directly from sunlight. The boiler (absorber) of such solar power plant is located on a tower at the focus point of a great focusing collector. Solar radiation is focused on it through many moveable flat mirrors - so-called heliostats [3]. In the boiler e.g. oil is heated, in the heat exchanger hot steam is obtained, which then drives a turbine, the turbine drives the generator that produces electricity (thermodynamic cycle).

Recently another variant of solar thermal power plants is being developed, where sunrays are concentrated through long horizontal parabolic mirrors into tubular glass absorbers (Fig. 1).

The vacuum glass tubes (each unit 4 m long) are made from a high transparent and resistant borosilicate glass. It is high resistant against wear and at the same time allows transmission of more than 96 % solar energy. A special oil is heated by to a temperature of 600 °C. In the heat exchanger hot steam is obtained that is then applied within the thermodynamic cycle - it drives the turbine, the turbine drives the generator and this then produces electricity.

Fig.1 Parabolic mirrors and glass absorbers [4]

These systems are mostly indicated as CSP (Concentrated Solar Power). Plants with these systems are frequently denoted as **thermosolar.**

In June 2007 the solar power plant on the basis of the CSP technology was put into operation with an installed capacity of 64 MW in Boulder City and in winter of the year 2008 another one with an installed capacity of 50 MW near the city of Guadix (Granada, Spain) [4]. However, under the desert conditions of California these plants have been worked since a half of the eighties.

The Guadix solar power plant (50 MW_e) has an approximate reflectance area of horizontal parabolic mirrors of 360,000 m^2 and for the steam production 15,000 glass absorbers is used about 60 km long (absorber is 4 m long). The total area of the plant is about 2 million m^2.

Recently the Desertec project is often presented made by Desertec Foundation. The company brings together about twenty major German investors (banks, energetic firms). The project assumes the building of concentrating solar thermal (CSP) power plants in North Africa in the area of the Sahara, which should partially solve the problems in covering electricity demand in Europe. Provided the project will be accomplished according to the plan, around the year 2050 after completing the building of all blocks it should cover the European consumption up to 15 %. Another (minor) part of electric power should cover the consumption in North Africa and the Middle East and also be used for fresh water production. The installed capacity should reach 100 GW, the project price should be EUR 400 billion [5].

A certain issue concerns the conventional (AC) transmission network not being capable to transmit large amounts of electricity over long distances. Therefore, it is planned to use a combination of traditional alternating current power grids and high-voltage direct current transmission lines over large distances (HVDC). The main advantage of HVDC is that it emits no harmful electromagnetic waves and can be led under surface and water. The costs on its building achieve far lower amounts than those on building the plants [5] .

3 FUEL CELL

The electricity may be obtained from solar energy also via chemical energy by decomposing water into hydrogen and oxygen [3] . Thereby the initial *radiation energy* will be stored as *chemical energy in both gases*. During compounding both gases, i.e. hydrogen oxidation, water occurs again. At the same time the accumulated energy is released either in the form of heat (in burning), or electric current in a fuel cell. A fuel cell is a transducer converting chemical energy into electrical energy.

The fuel cells will likely be - just as nuclear fuel - an important resource of electrical energy in future. They represents stored solar energy and can be obtained in unlimited amounts. Efficiency of fuel cells is high (up to 90 %), while the generators of fossil fuel power plants achieve only 35 ÷ 38 % (in perspective 50 %).

Operation of fuel cells is absolutely clean as their product is water. Such cells operate totally noiselessly, as they involve no moving parts. Using fuel cells, electricity can be obtained for households (with an output of 12 kW). However, batteries of many fuel cells are being produced now with a capacity of up to 13,000 kW (these are used especially in astronautics). Fuel cells can be also used to drive vehicles.

4 INDIRECT CONVERSION

Indirect conversion in obtaining electricity from solar energy results from generating heat using solar collectors. At the focus point of collectors thermoelectric couples are located converting heat into electricity. Thermoelectric conversion is based on the so-called Seebeck effect (electric current occurs in a circuit of two different conductors provided that their connections have different temperatures). The simple device of two different conductors connected at their ends is known as a thermoelectric couple. Its efficiency depends on properties of both metals, which the conductors are made from, and on the temperature difference between the warm and cold connections. A larger number of thermoelectric couples properly connected are called a thermoelectric generator [3] .

5 DIRECT (PHOTOVOLTAIC) CONVERSION

Direct conversion utilizes a photovoltaic effect, in which a specific substance struck by light (photons) emits electrons. This phenomenon may occur in some semiconductors (e.g. in silicon, germanium, cadmium sulphide etc.). **Photovoltaic cell** is usually formed by a thin plate of single crystal silicon, however also a polycrystalline material may be used. The plate is from one side enriched by atoms of a trivalent element (e.g. boron), on the other side by atoms of a pentavalent element (e.g. arsenic). While photons fall on the plate, negative electrons are released leaving positively charged "holes" (electrons and holes are separated by an internal electric field of PN junction). Attaching electrodes to both sides of the plate and connecting them by a conductor, electric current will start flowing through. One cm^2 gives a current of about 12 mW (mili-watts). One square metre of solar cells can give at summer noon up to 150 W DC. The solar cells are connected either in series to achieve the required voltage (0.5 V per cell), or in parallel to get high electrical current. By default, assemblies are used for DC nominal operating voltage of 12 or 24 V.

Thus formed assemblies of cells in serial or serial/parallel sequencing are sealed within the structure of coating materials of a resulting **solar panel**. Solar panel structures have been adapted to all kinds of applications. Most of solar panels are equipped with a front cover glass and solar cells are laminated into a structure of plastic plates (Fig. 2). Solar panels may take the form of façade glazing, roofing or façade cladding. Great demands related to mechanical and climatic stability are laid to solar panels so as to ensure their long life (temperature, humidity, wind). Coatings must have a high optical and isolation durability. The life expectancy of panels is more than 30 years [16]. The manufacturer's guarantees are usually set so that the panel output does not drop below 80 % of the initial output after 25 years [6] .

Fig. 2 Photovoltaic power plant with an installed electric output of 2.2MW in Althegnenberg (Ger.) [8]

Development of solar cells has come to a number of various technologies. The most sophisticated and stable is the technology based on crystalline silicon. The basis is a 0,20 ÷ 0,3 mm thin slice of silicon with mono- or polycrystalline structure. Usually these are the slices of square shape with dimensions of 200 x 200 mm. Efficiency of converting sunlight into electricity varies for the actually mass-produced silicon solar cells from 14 to 17 %. Efficiency related to laboratory samples achieves up to 28 %. The cells excel in their high output stability and long life (minimum 30 years). The mere production of silicon slices is relatively quite energy intensive. However, the amount of energy invested in manufacturing a solar panel is produced by this panel in our country within 5 years. Nearly 85 % of all solar panels are made with silicon crystalline cells.

Solar panels made by thin-film technology, also known as the second generation technology, take a major position in the market, too. Solar cells, including their connections, are built directly on a bearing underlay by deposition of very thin layers of materials (units of micrometers). Such bearing underlay can be a glass, plastic or steel sheet. The most commonly used material for active layers is again silicon, however, this time with an amorphous or microcrystalline structure. Efficiency of thin-film silicon panels is 7 ÷ 9 %. Meanwhile, panels in small volumes are made by the thin-film technology with the structures of CdTe, CIS and CIGS (copper, indium, gallium, sulphur, selenium). Efficiency of the CdTe structure is 12 % and CIS structures achieve up to 15 %. Although thin-film solar panels are still lagging behind efficiency values of crystalline silicon cells and yet provide a significant cost advantage, these structures promise to reduce considerably the price of photovoltaics. A panel of CIS thin-film structure has approximately a half energy return (about 2.5 ÷ 3 years) compared to a classical panel with crystalline silicon [7] .

Alternative technologies (polymers and cells with photosensitive pigments), for which significantly lower production costs are expected, are at the stage of laboratory tests. For solar cells of the third generation with alternative technologies very high efficiency values at relatively low costs are then expected. However, these technologies are still at an early stage of development.

To use electricity from solar panels it is necessary to connect to the panel, except for electric appliances, another technical features - as accumulator batteries, regulator pack, voltage inverter, indicating and measuring instruments, or perhaps a system of manual or automatic turning towards the Sun. The assembly of photovoltaic panels, supporting equipment, appliances and possibly other elements is called the **photovoltaic system**. Quantity and composition of photovoltaic system elements depends on the type of application.

Through the use of positioning units it is possible to increase the output of a photovoltaic system by 37 % compared to a classical non-positioning installation. An intelligent control unit (PLC) in connection with a special sensor-based head provides both precise positioning and maximum utilization of sunlight (even under cloudy weather). Such positioning can be controlled by both sensors and manually. Such positioning unit consumes a low energy amount and is powered from the network. Due to sufficient safety even in very strong wind the unit is usually fitted with a wind speed sensor. In case of large solar parks the positioning units are being managed and monitored by a central control system. With this tool, you can track practically on-line conditions of all positioning units and inverters. All you need is an Internet connection and so have the solar park whenever under the control from any place.

In our country a photovoltaic system with an output of 1 kW is capable to produce 900 ÷ 1 000 kWh of electricity per year.

Grid independent systems (off-grid), so called **island systems**, are installed in locations, where it is not advisable to build an electric connection. Thus, in cases, where the costs of building the connections are comparable with the costs of photovoltaic system (distance from the grid more than 500 ÷ 1000 m). Outputs of island systems are in the range of 1 W ÷ 10 kW of peak power output.

The grid independent systems may be divided into the systems:

- ***With direct power supply*** (connected electrical equipment is functional only during solar radiation of sufficient intensity; it is a simple connection of a solar panel and an appliance),
- ***With accumulation of electrical energy*** (used where electricity is needed even at a time without sunlight; they uses rechargeable batteries),
- ***Island hybrid systems*** (the system extension by an additional source of electricity covering the demand for electric energy during periods of insufficient sunshine - such source may be a windmill, small-scale hydropower plant, electro-central, cogeneration unit etc.).

On-grid photovoltaic systems are most applicable in areas with a dense electricity network. Electricity is supplied from solar panels via mains inverter into the grid. The systems of this type operate absolutely automatically due to the microprocessor control of the grid converter. Peak capacity of photovoltaic systems connected to the grid varies from kW to MW.

Photovoltaic panels in case of on-grid photovoltaic systems are often integrated into the building envelope. The most widespread they are in Germany, Japan, USA and Spain. Several larger systems of this type have been implemented in the Czech Republic.

From large foreign installations in the field of photovoltaics in recent time we can recall e.g. the initiative of the German company Phoenix Solar AG, which together with the financial partner KGAL put in early April 2008 into normal operation its largest solar park located next to the town of La Solana in Spain (Fig. 3). The solar power plant is located in the area of Castilla-La Mancha, about 200 km south of Madrid.

Its installed capacity is 6.5 MW and since the end of March 2008 it puts green electricity into the grid of the Denisa company for local use. An expected hour capacity of the La Solana power plant is 1,580 kilowatt-hours. It is enabled by installing 40,320 glass modules on the area of about 21 hectares, which should provide an annual energy gain of about 9.8 million kWh. Such amount of electricity can be used by approxiately 11,000 consumers of La Solana, which is about 70 % of population of the Spanish town [9].

However, the largest photovoltaic solar power plant in Spain is today the power plant in Olmedille, having an output of 60 MW_e.

Fig. 3 Photovoltaic power plant, having an installed capacity of 6.5 MW in La Solana (Spain) [8]

The French company EDF will have built by 2012 at an abandoned Air Force Base of NATO in Toul-Rosieres nearby the town of Metz on the area of 145 ha the largest photovoltaic power plant in the world with an capacity of 143 MW_e to meet electricity needs for approximately 62,000 people.

Among important recent installations in the Czech Republic we can remember e.g. the photovoltaic power plant (PV system) in the village of Přimda from early 2008 [10]. The investment of CZK 48.5 million involves except the photovoltaics itself also the electric connection, switchboard, transformer station, fencing and the cost of the project.

The installed capacity of the PV system is 439.65 kW_p, built-up area 12 ha. The return of the project is expected in the range of 8 ÷ 10 years.

For the power plant polycrystalline panels Mitsubishi were used (PV-AD 185MF5 panel type, P_{max} = 185 W_p, V_{oc} = 30,6 V, I_{sc} = 8,13 A, V_{mp} = 24,4 V, a module weight of 17 kg, dimensions 1,658 x 834 mm). The used inverters of the company Power One - Aurora PVI-6000-OUTD-DE. The number of installed panels is 2,376 pcs, the number of inverters then 66 pcs.

This Šumava region shows since 1956 by long-lasting measurements of the meteorological station in Přimda at 742 m above sea level the following data:

Number of sunny hours: ranging from 1 400 ÷ 1 800 hours/year, the lowest total amount of sunshine: 1,258 hours/year (1977), the highest total amount of sunshine: 2,106 hours/year (2003), the highest monthly total sunshine: 342 hours/month (July 2006), in the last decade two years were with an annual total amount of sunshine over 1,800 hours.

Among all recent photovoltaic installations in our country we can further mention the equipment in Ostrožská Lhota. In early 2008 the photovoltaic power plant, which until then had an installed capacity of 702

kW_p, was extended by the second block with an output of 920 kW_p. So in total the solar park in Ostrožská Lhota has reached an installed capacity of 1.622 MW_p. The planned future annual supply of electricity into the grid is about 1,600 MWh.

However, today in the Czech Republic also photovoltaic power plants with a far higher output (10 MW_e) are prepared.

From the above it is obvious the solar energetics in the Czech Republic based on photovoltaic conversion develops recently very rapidly. In late 2008, the installed electric capacity of solar power plants achieved in our country the value of 54.3 MW, at the end of March 2009 according to the statistics of the Energy Regulatory Office there were solar photovoltaic panels, having a total installed electric output of 67.3 MW, in the territory of the Czech Republic [11]. In early February 2010 the installed capacity of the photovoltaic power plants then reached 485.73 MW_e, which represents a very fast growth. For comparison it may be noted that the installed capacity of windmills in early February was only 193.36 MW_e.

Very rapid development of PV is evident not only here, but also for several years in Germany, Spain, Greece, Italy, France, USA or Japan [6]. The current output of photovoltaic power plants in Spain is 1,671 MW_e, in Germany then 1,505 MW_e.

By Act No. 180/2005 Coll. [12] the grid operator in the Czech Republic is obliged to source electricity generated by a photovoltaic power plant at a rate set by the price decision of the Energy Regulatory Office [13]. The purchase price of electricity delivered into the grid was according to this decision till the first half of March 2010 given for photovoltaic power plants in the range of 12.79 ÷ 12.89 CZK/kWh. The rate of 12.79 Kč/kWh applied to the photovoltaic power plants having an installed capacity over 30 kW, the rate of 12.89 Kč/kWh then for the photovoltaic power plants with an installed capacity not higher than 30 kW.

With respect to the very rapid growth of installed capacity (see above) it is assumed that the majority of grant funds intended for renewable energy resources will be paid out to the operators of photovoltaic power plants, and other renewable resources will remain without subsidies. Furthermore, the purchase price of electricity for other renewable energy sources is considerably lower. For example, for windmills put into service after January 1st, 2010 including, it is 2.23 CZK/kWh.

A huge investor interest in photovoltaics is mainly due to significant interim decrease in specific investment costs of these resources caused by the decrease in prices of photovoltaic panels by more than 40 % [14]. However, the Energy Regulatory Office cannot react to this situation by an adequate decrease in purchase price of electricity from such sources, as it is allowed by law [12] to reduce the interim purchase price of electricity for new sources by 5 % only. It results in very noticeable preferences of new built photovoltaic power plants compared to other types of renewable resources, where support is set optimally.

The occurred situation results also in a speculative blocking of connecting capacities at the level of distribution systems. For this reason, it is no longer possible for a significant part of the Czech Republic in the foreseeable future to issue a positive opinion on the connection requests for any applicants. This applies not only to the renewable resources, but also the resources for combined heat and power systems.

Finally, it is necessary to underline the financial and social aspects of the whole problem, when the occurred uncontrolled development of photovoltaic resources already now means that all customers in the Czech Republic purchasing electricity, including households, public administration and self administrations, will in 2010 contribute specially to the new photovoltaic resources by more than CZK 3 billion, while the total fund to support all types of renewable resources in 2008 amounted to CZK 2.658 billion. It can be simply stated that the price of electricity for all customers in the Czech Republic for the year 2010 just by reason of the development of photovoltaics will be raised by about CZK 50/MWh.

Further, it is estimated that at least CZK 15 billion, but perhaps 25 billion crowns, the Czechs will pay under the Energy Regulatory Office within two years in electricity prices for the support of photovoltaic energy. For an idea, it is CZK 1,500 to 2,500 per capita of the country, including children and pensioners [15].

Therefore, on March 17, 2010 by the Chamber of Deputies of the Parliament of the Czech Republic the bill was adopted to amend Act No. 180/2005 Coll. [14], which allows reducing the purchase price of electricity from photovoltaic power plants.

6 CONCLUSION

Finally, it should be noted that the purpose of this paper was to provide a summary of basic information about the current solar energetics, because there is fixed in the public subconscious mainly just the existence of photovoltaic solar power plants.

In Annex of Act No. 100/2001 Coll., assessing the environmental impact and amending some related Acts (Act on the assessment of environmental impact), as subsequently amended, the projects of solar energetics are not included. The process of assessing the environmental impact also does not know the concept of photovoltaics.

From the above reasons, today in the Czech Republic the plans in the field of solar energy are not subject to the process of assessing the environmental impact [2].

It is not a good situation, as in future great difficulties could occur related to removal of the photovoltaic equipment, since in the absence of the process of assessing the environmental impact no conditions are set either in the subsequent processes (zoning, building permits), which would clearly identify individual actions and operators' responsibilities in liquidation of these devices.

It is not possible to ignore either further impact on the environment, which is the impact on the landscape. For instance the plants having an output of 10 MW_e represent a great land occupation (ca 10 ha), although temporary, which is closely related to the impact on the landscape (according to Article 12 of Act No. 114/1992 Coll., on nature and landscape protection, as subsequently amended). This impact is in most cases totally ignored.

REFERENCES

[1] HERČÍK, Miloslav, LAPČÍK, Vladimír, OBROUČKA, Karel. *Ochrana životního prostředí pro inženýrské studium*. Skriptum. Ostrava: VŠB-TU, 1994. 243 s.

[2] LAPČÍK, Vladimír. *Výrobní technologie a jejich vliv na životní prostředí* (monografie).

VŠB-TU Ostrava, HGF, IEI, 2009. ISBN 978-80-248-2015-6. 362 s.

[3] http://www.alternativni-zdroje.cz/slunecni-solarni-elektrarny.htm

[4] http://www.schottsolar.com

[5] STÁREK, Václav. *Evropskou žízeň po energii může uhasit Sahara*. In E15 – 15 minut pro ekonomiku & byznys, 2009, č. 408, s. 12 - 13.

[6] KLIMEK, Petr. *Deset dobrých důvodů pro fotovoltaiku*. In Alternativní energie, 2008, č. 4, s. 20 – 21.

[7] Kol. autorů. *Obnovitelné zdroje energie a možnosti jejich uplatnění v České republice* (II. vydání). Praha: ČEZ, a.s., 2007. 183 s.

[8] http://www.phoenixsolar.com/SolarPowerPlants/Case_Studies/

[9] KUČERA, Zdeněk. *Ze španělské La Solany 6,5 megawattů*. In Alternativní energie, 2008, č. 2, s. 9.

[10] KUČERA, Zdeněk, STEJSKAL, Jindřich. *Nová FVE Přimda*. In Alternativní energie, 2008, č. 2, s. 8.

[11] ZELENKA, Robert. *Solárních elektráren rekordně přibývá*. In E15 – 15 minut pro ekonomiku & byznys, 2009, č. 380, s. 8.

[12] Zákon č. 180/2005 Sb., o podpoře výroby elektřiny z obnovitelných zdrojů energie a o změně některých zákonů (zákon o podpoře využívání obnovitelných zdrojů).

[13] Cenové rozhodnutí Energetického regulačního úřadu č. 8/2008 ze dne 18. listopadu 2008, kterým se stanovuje podpora pro výrobu elektřiny z obnovitelných zdrojů energie, kombinované výroby elektřiny a tepla a druhotných energetických zdrojů.

[14] Sněmovní tisk 968: Vládní návrh na vydání zákona, kterým se mění zákon č. 180/2005 Sb., o podpoře výroby elektřiny z obnovitelných zdrojů energie a o změně některých zákonů (zákon o podpoře využívání obnovitelných zdrojů).

[15] Za podporu solární energetiky zaplatí Češi v účtech až 25 miliard. In E15 – 15 minut pro ekonomiku & byznys, 2010, č. 542, s. 1.