Photovoltaics – The Present and the Future

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Received July 10.2014; accepted July 30.2014

Summary. The paper presents the possibilities of generation of electric energy with the use of solar cells operating on the basis of absorption of visible-range radiation and the photovoltaic effect. This study presents the advantages and disadvantages of photovoltaics and examples of the application of solar cells in industry and agriculture. Due to high investment costs, the development of photovoltaics is supported in many countries of the world through systems of subsidies or systems of fixed tariffs, which considerably enhances its attractiveness.
Key words: photovoltaics, solar radiation, BIPV.

INTRODUCTION

One of the greatest challenges facing humanity is the replacement of shrinking resources of fossil fuels with renewable sources of energy while meeting the demand related with growing energy consumption all over the world. The solution to that problem is the development of an inexpensive method of utilisation of generally available sources of energy such as the Sun, water or wind, that nature has been using for millions of years. At present, the most dynamic development is noted in the case of solar energy. We can observe a considerable increase of interest manifested in the installation of solar panels and photovoltaic cells on the roofs of houses and in other places such as road signs or poster pillars. It is becoming more and more economically viable to build large installations, called solar farms, that provide electric power for large numbers of individual consumers. Special possibilities of application of that form of electric power acquisition are related to the so-called "small" power generation systems, especially those used in agriculture, where photovoltaics is utilised in such processes as agricultural produce drying, greenhouse production or storage of food products in cold-storage facilities.

There is an increasing tendency to implement programs supporting the growing utilisation of renewable energy sources. National governments place a strong emphasis on the diversification of energy sources, with the aim of reducing the exploitation of conventional resources and of lowering the levels of CO_2 emissions to the atmosphere. European countries more and more willingly revise their legislation to support the use of renewable energy sources, and the basis of energy policy till 2020 is the Program 3×20 which includes the following provisions:

- 20% reduction of greenhouse gas emission relative to the level of 1990,
- 20% reduction of energy consumption,
- 20% increase of the share of energy from renewable sources in the global EU energy production by the year 2020 [1].

SOLAR RADIATION AS A SOURCE OF ENERGY

The Sun is the most powerful source of light reaching the Earth. It emits energy generated as a result of thermonuclear reactions taking place in the Sun. The radiation emitted by the Sun covers all the ranges of electromagnetic wavelengths. The greatest amount, i.e. 49% of energy from the spectrum of solar radiation, is emitted in the range of visible radiation (wavelengths of 380÷760 nm) [2]. Waves with lengths greater than 800 nm transmit 44% of solar energy, and 7% of that energy is emitted in the near-UV range (120÷300 nm). X-ray radiation and far-UV account for not more than 0.001% of the total energy. The Sun is also a source of radio-frequency waves (wavelengths above 1 mm). However, the energy of that radiation is negligibly small (of the order of 10^{-10} %) [3].

Photovoltaics makes use of that part of solar radiation spectrum which is generated in the photosphere, i.e. in the upper layer of the convective zone of the Sun. When solar radiation passes through the Earth atmosphere, the photons of solar radiation react with atoms, molecules, aerosols and liquids contained in the atmosphere, on the pathway of two physical phenomena:

- absorption of radiation with the direction of wave propagation unchanged. The fundamental components of the atmosphere on which radiation absorption takes place include ozone (O_3), carbon dioxide (CO_2) and water vapour (H_2O). Ozone absorbs UV radiation, while carbon dioxide medium IR, and water vapour – wavelengths from the ranges of near and medium IR;
- scattering, i.e. change of the photon trajectory under the effect of contact with particles of dusts or aerosols contained in the atmosphere. Depending on the size of the scattering particles, the particular wavelengths are scattered in various ways.

Those two factors determine the atmospheric transmittance coefficient whose value is lower than 1. According to the Lambert-Beer Law, it leads to the reduction of radiation intensity proportionally to the path length through the atmosphere which is characterised by the value known as the air mass index (AM). AM is the parameter determining the optical path that has to be travelled by solar radiation passing through the atmosphere, normalised to the shortest possible pathway (when the Sun is in the zenith position). It is expressed by the following formula [4]:

$$AM = \frac{1}{\cos\theta}, \qquad (1)$$

where:
θ – angle of deflection in the vertical plane (zenith angle).

The spectrum of solar radiation outside the atmosphere, denoted as AM0, is similar to black-body radiation spectrum at the temperature of 5743 K, and its total radiation intensity amounts to 1365 W/m². Whereas AM1 refers to the situation when $\theta = 0^o$, which means that the Sun is in the zenith (equatorial zone) and is equal to circa 0.7 AM0. In accordance with the adopted standards ASTM E 892, IEC 60904-3, unified for ease of results presentation, for the simulation of photovoltaic cells operation the coefficient of AM1.5 is used that relates to solar radiation in the situation when $\theta = 48.2^0$ and its intensity is 1000 W/m² [5]. Such conditions are used in the tests of photovoltaic cells aimed at the determination of their peak power, denoted on the modules as W_p.

Solar radiation is characterised by a variety of values, the most important of which are the following:

- **radiation flux** – radiation energy passing through a given surface in a unit of time (radiation power) Φ_e [W],
- **global radiation** G or E [W·m^{-2}] which is the sum of direct and scattered radiation, and sometimes also of radiation reflected from the surroundings. Global solar radiation is defined as the radiation intensity on a flat horizontal surface, incoming from the entire hemisphere of the sky,
- **irradiation** H [kWh·m^{-2}], composed of the sum of direct irradiation (frequently called insolation), scattered and reflected irradiation, representing the energy received by a unit of surface area within a specified time,
- **insolation** h [h] presented by means of average numbers of hours with directly observable operation of the Sun; occasionally it is referred to as e.g. the annual sum of insolation.

In the territory of Poland insolation varies within the range of 950 – 1250 kWh/m², while the mean time of operation of the Sun amounts to 1600 hours per year. Approximately 80% of the total annual sum of insolation is accounted for during the six months of the spring and summer season [4].

The energy of electromagnetic radiation from the Sun can be utilised in various processes of its conversion to other kinds of energy. Solar energy can be converted to the following kinds of energy:

- photothermal, when solar energy is converted to thermal energy (heat),
- photochemical, consisting in the binding of solar energy in chemical bonds,
- photovoltaic, utilising the photovoltaic effect during which electric energy is produced.

The most popular and widespread type of renewable energy generation is the photovoltaic conversion. The photovoltaic effect was first observed by Becquerel in 1839, in a circuit of two illuminated electrodes coated with AgCl or AgBr and immersed in an electrolyte. However, it was not until 1876 that Adams and Day succeeded in achieving that effect on a junction of Pt and Se, which permitted to conclude without a doubt that direct conversion of solar energy into electric power was possible [6]. The theoretical foundations of the photoelectric effect were developed on the basis of quantum mechanics in the years 1920-1930. Nevertheless, the strongest impact on the advancement of solar cells was the development, by Czochralski, of the method of obtaining silicon crystals of high purity [2].

PRINCIPLE OF OPERATION OF PHOTOVOLTAIC CELLS

The first semiconductor cell based on a p-n junction was formed during the slow crystallisation of molten silicon and described by Russel Ohl in 1941. The research on its properties permitted the understanding of the role of p and n admixtures in controlling the properties of the semiconductor, and thus led to a revolution in microelectronics [6].

The principle of operation of all photovoltaic systems is based on the phenomenon of separation of charges on the junction of surfaces of two materials differing in the conductance mechanism. The fundamental structure of a solar cell is constituted by a strongly doped n-type area, i.e. the emitter, and a less strongly doped p-type base. During the exposure of such a semiconductor junction to light, the incident photons can generate an electron-hole pair of charges, which causes the generation of electromotive force on the junction. The generation of an electron-hole pair can take place only in the boundary layer of the junction. The carriers are separated, as within the area of the junction they are affected by electric field formed as a result of contact of two semiconductors with different conductance character. Due to that field, electrons and holes start moving in opposite directions resulting in their separation, the effect of which is the formation of an external electric tension on the junction, i.e. the photovoltaic effect takes place (Fig. 1.). If a receiver is connected to the terminals of the junction, electric current will flow as long as photons keep falling on the cell. Only those photons participate in the generation of current carriers in the junction whose energy is greater than the semiconductor energy gap (or band gap) E_g, and in the case of silicon that condition is met by 30% of the spectrum range of solar radiation [3].

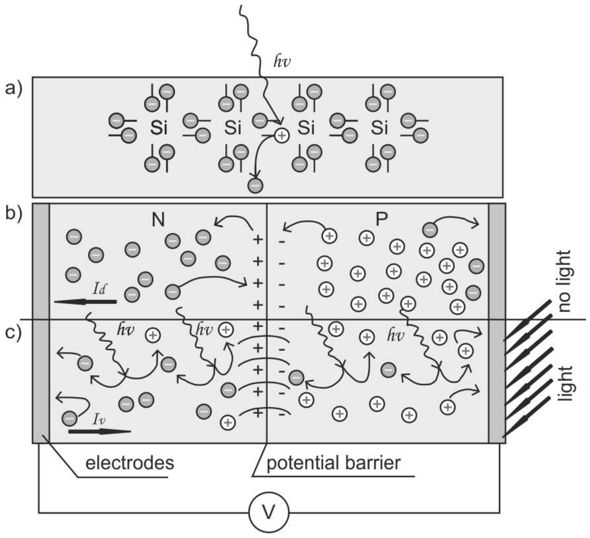

Fig. 1. Mechanism of photovoltaic effect: a) mechanism of generation of positive charge, b) flow of reverse diffusive current (no light), c) current flow (with light) [2]

The p-n junction based silicon cell is characterised by plotting the I-V curve, i.e. the graph presenting the intensity of output current of a photovoltaic generator as a function of voltage at a certain temperature and defined radiation intensity. The curve includes a number of points, presented in Fig. 2, which provide information on the basic parameters of the cell, as follows:

1. open circuit voltage (U_{oc}) – voltage on the terminals of an unloaded photovoltaic generator at a certain temperature and defined radiation intensity,
2. short circuit current (I_{sc}) – output current intensity under short circuit conditions at a certain temperature and defined radiation intensity,
3. P_{max} – maximum power point and its coordinates: U_{mpp} and I_{mpp}.

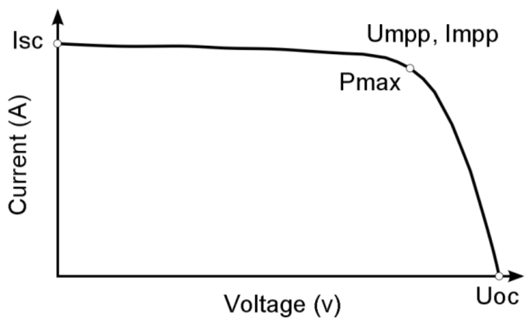

Fig. 2. Current-voltage curve of solar cell

The efficiency of photovoltaic conversion is defined as the ratio of output electric power to the total power of incident radiation [7]:

$$\eta = \frac{U_{oc} \cdot I_{sc} \cdot FF}{S \cdot A}, \qquad (2)$$

where:
U_{oc} – open circuit voltage [V],
I_{sc} – value of short circuit current [A],
S – cell surface area [m²],
A – power of radiation falling onto the cell surface [W·m⁻²],
FF– fill factor – parameter determining the performance of a photovoltaic cell [7]:

$$FF = \frac{U_{mpp} \cdot I_{mpp}}{U_{oc} \cdot I_{sc}} \cdot 100\%, \qquad (3)$$

I_{mpp} – value of current intensity at maximum power point [A],
U_{mpp} – voltage at maximum power point [V].

The value of the fill factor is always lower than 1 and, like open circuit voltage, depends on the structure and type of the semiconductor layer, the level of doping of both areas of the p-n junction, and on the level of the inbuilt potential barrier and temperature of the junction. Very good cells are characterised by values of $FF > 0.8$ [8].

At present, the mass-produced solar cells have efficiency exceeding 20%. There is ongoing work on improving the efficiency of solar cells that would lower the costs of energy generation and result in shorter time of recovery of investment costs involved in the purchase of photovoltaic cells, and in increased competitiveness of such systems relative to other alternative sources of energy.

KINDS OF PHOTOVOLTAIC CELLS

Currently, thanks to intensive development of research on photovoltaics, we can speak of four generations of solar cells. The first generation cells are based on silicon, the second most common element – after oxygen – on Earth. In nature it occurs primarily as a dioxide, being a component of e.g. quartz contained in the crust of the Earth. That compound is used to obtain, via chemical transformations, metallurgical silicon with 98% purity, that is next subjected to purification to obtain high-purity silicon.

Silicon monocrystals are obtained primarily with the method of Czochralski and with the method o zonal melting. Silicon blocks formed in that manner are cut into thin plates, with about 40% material losses. Next, using the method of diffusion, the p-n junction is formed in the silicon, an antireflection layer is applied, and metal (usually silver) electric terminals are inserted. In some cases surface texturing is applied to enhance the operation parameters of the cell.

Solar cells are also built using multi-crystal and poly-crystal silicon, with grain sizes from 1 mm to 1 cm and from 1 μm to 1 mm, respectively [6]. In that case silicon blocks are produced with the method of Bridgman or of block casting. However, the efficiency of such cells is lower than that of the single-crystal ones, and amounts to 14-15% [9].

For the needs of photovoltaics also silicon tapes and foil sheets are produced, permitting material losses during the cutting of large silicon blocks. The schematic diagram of a typical solar cell is presented in Fig. 3. It consists of a single p-n junction. The p-type silicon base is around 200 µm thick whereas the n-type emitter is around 100 µm thick. An antireflection coating layer is deposited over the emitter in order to minimise reflection losses. Metal contacts are placed at the bottom of the cell as a whole layer and at the top as fingers. Approaches for increasing the efficiency include making inverted pyramids at the surface, buried contacts, selective emitters and so forth. At present, c-Si solar cells have reached record efficiencies near 25%, for which the top and bottom surfaces have been well passivized. The theoretical values of efficiency for other silicon cells are as follows: for poly-crystalline silicon – 20,4%, for amorphous silicon – 10% [10].

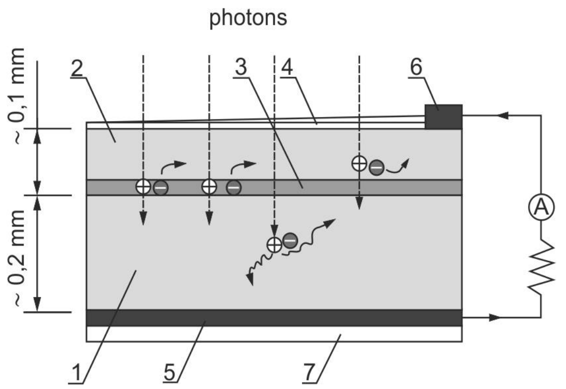

Fig. 3. Simplified schematic diagram of photovoltaic cell from crystalline silicon : 1 – p-type semiconductor, 2 – n-type semiconductor, 3 – boundary layer, 4 – antireflection coating, 5 – anode, 6 – cathode, 7 – base plate

Commercial cells of the first generation are characterised by efficiency in the range of 17-22%. Their production costs are high, mainly due to the relatively low level of automation of the production (many operations have to be performed by a qualified worker) and to the high cost of the necessary components. The current market share of cells of that type is about 63% [11].

The second generation cells are the thin-film. The reduced amounts of materials used in their production permitted a significant reduction of the production costs. The thin-film semiconductor structures are obtained primarily with the method of molecular beam epitaxy, liquid phase epitaxy and chemical vapour deposition. Their production requires the use of bases with high mechanical strength, e.g. low-quality silicon, glass, ceramic materials or graphite. The outer layer of the cell is usually textured to increase the active surface area. At present there are a number of kinds of thin-film cells on the market, utilising various materials like e.g. amorphous silicon, or multiple layers of amorphous and microcrystalline silicon, notably enhancing their efficiency.

Apart from the silicon cells, technologies are being developed that utilise such compounds as GaAs, CdTe, or the system of copper – indium – gallium – selenium (CIGS), with the highest efficiency achieved in laboratory conditions being 36.9% [10], and in the case of commercial cells 18.4% [11]. The high efficiency of those cells is mainly due to the fact that the range of absorption of radiation is shifted towards the visible radiation, which causes that the temperature effects, considerably reducing the operation parameters of cells, are lower and thus the cells can be used as covering of the facades of buildings. The application of new inorganic materials and cell production methods such as the screen process and spray pyrolysis notably reduced the costs of production and permitted the application of very thin layers on flexible base materials (metal, plastic, etc.).

The second generation cells are now more and more popularised by their manufacturers. This is related with the possibility of their wholly automated production and lower price of the components used than is the case with the first generation cells. As a result of this their market share is constantly growing.

The third generation cells include photoelectrochemical cells among which we can distinguish organic cells, polymer cells and dye-sensitised solar cells (DSSC). In those structures the photovoltaic effect does not take place in the traditional sense. The functions of the semiconductor in the conventional solar cells are separated, and other organic materials are used for the absorption of radiation. Thanks to their simple structure and cheap components, they are perceived as an opportunity for rapid development of widely available technology of production of solar cells. The main obstacle for their popularisation is their low efficiency, oscillating at the level of several percent in the case of commercial applications. Their present market share does not exceed the level of a fraction of a percent, and the most popular ones are the polymer cells of the "power plastic" type produced by Konarka. The phenomenon of those cells consists in the fact that the alternating single and double bonds occurring in polymers cause that they behave like a semiconductor. A slight modification of the structure of the polymer chain may lead to the creation of materials with such properties as those of rubber or linoleum, which in the case of the production of solar cells permits to impart to them any shape required, and to modify their colour [12].

In recent years we have witnessed the slow development of the fourth generation of solar cells, comprising the latest achievements of research. Those include, among other things, structures making increasingly frequent use of the methods of nanotechnology, such as e.g. quantum dot cells which appear as a substitute of the sensitising agent (dye) in DSSC. That group includes also the so-called plasmon cells, in the case of which on the surface of the semiconductor layers of surface plasmons are applied, bound with nanoparticles, that cause an amplification of light absorption, reduce internal recombination effects, and notably improve the parameters of the cells [13].

PHOTOVOLTAICS SYSTEMS

In practice electric power is generated with the use of both individual cells and complex systems with power ratings of up to tens of MW. Large solar power plants, built of thousands of single photovoltaic cells, can be encountered all over the world, and the biggest of those, the target power rating of which is to be 500 MW, is currently being built in the USA. In Poland the largest installation of this type, with power rating of 1 MW, is situated in the locality of Wierzchosławice (Małopolskie Province).

Next to the large solar power plants, a notable group of producers of renewable energy are individual consumers who install photovoltaic cells in their households, on the roofs of buildings. Photovoltaic cells can also be found in many portable devices, e.g. portable refrigerators, garden lamps, road signs power supply systems, phone chargers, mechanical toys, as well as supplementary energy supply systems in cars, airplanes or yachts.

Photovoltaic systems currently in use can be classified in the following groups:

- consumer-use electronic equipment,
- stand-alone systems (off-grid),
- systems connected to the grid,
- hybrid systems (operating in conjunction with other power generation systems),
- special purpose devices.

Large photovoltaic systems are most often connected to the grid. In such a case they require the use of additional equipment such as inverters, as the cells produce direct current. The function of the inverters is not only to convert direct current to alternating current, but also to maintain at correct levels the parameters characterising the quality of electric power (voltage, frequency, time profile, supply continuity) in conformance with the European standard PN-EN 50160:1998. Such systems are most frequently connected to the grid, which solves the problem of energy transport over long distances.

In the case of stand-alone systems, apart from inverters it is also necessary to foresee some energy storage systems. At present those are most often arrays of batteries, the quality of which largely determines the efficiency of the whole power generation system. Apart from storage batteries it is also possible to use systems converting electric power into other useful forms of energy, e.g. heat pumps which – supplied by solar cells – can generate heat for house heating or for heating water.

In agriculture it is possible to utilise hybrid systems combining the production of heat and electric power (systems composed of photovoltaic cells and an air or liquid heat converter). In such a case solar radiation falling on the surface of the photovoltaic cell is transformed into electric energy, and the heat generated in the course of the process, a negative phenomenon in solar cells, is taken off by air flowing above the cell or by a liquid flowing beneath it, depending on the type of the device structure. During the absorption of the heat the photovoltaic cell is cooled, and thus its efficiency is improved [14]. Systems of this type can be used e.g. during the drying of agricultural produce, for drying of biomass for the production of fuels or for the heating and lighting of greenhouses [15]. The schematic diagram of such a device is shown in Fig. 4.

Stand-alone systems are also used in agriculture for such functions as e.g. the supply of electric fences on pastures or of systems pumping water to reservoirs for the irrigation of crop cultures or for farm animals.

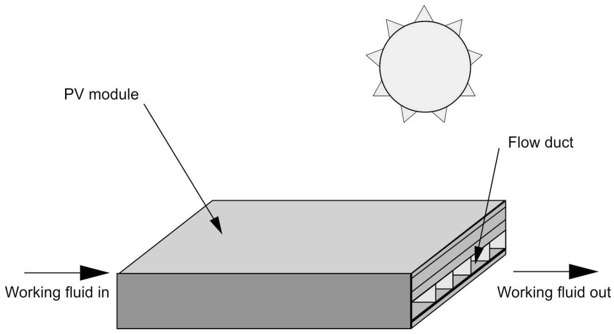

Fig. 4. Schematic diagram of a photovoltaic–thermal collector with water heating

Apart from systems generating electric power alone, photovoltaic cells can also be encountered in co-generation and tri-generation systems, in which heat and refrigeration are produced in conjunction. Such systems can be used successfully in the food industry that utilises large amounts of all of those kinds of energy.

BUILDING INTEGRATED PHOTOVOLTAICS

Attempts have been undertaken at integrating photovoltaic systems with buildings (BIPV – building integrated photovoltaics). In its concept, BIPV strives to create the maximum of possibilities of utilisation of the surface area of a building for the production of electric power. A typical example is the covering of the south-facing facades of buildings with photovoltaic panels. In such an application, the panels replace conventional facade materials, which reduces the cost of the facades as such, and thus also the total investment cost. Until recently the main problem facing such a solution was the visual effect, as facades covered with photovoltaic panels were simply ugly. However, now the market offers both coloured and flexible-based photovoltaic panels, so their application depends only on the imagination and vision of the architect, and additionally makes the building appearance more modern and environment-friendly. BIPV systems can be either stand-alone ones or grid-connected, and their primary advantage is that they make the building cheaper to maintain as the photovoltaic panels generate power at the peak-load times, permitting the limitation or substitution of using the most expensive power provided by the power supply grid. That requires careful analysis and selection of tariffs offered by the power supply operators.

Other advantages of BIPV systems include the following:

- Integration of the photovoltaic modules into the building envelope in a so-called "non-ventilated facade", both on public buildings such as office complexes, production buildings, shopping centres or schools, and on private buildings such as indoor gardens or terraced houses. The modules replace traditional building materials (e.g. spandrel glass) in a new structure and create an ambient inside temperature all-year round,
- "Ventilated facades" can be installed on existing buildings, giving old buildings a whole new look. These modules are mounted on the facade of the building, over the

existing structure, which can increase the appeal of the building and its resale value [16],
- Possibility of incorporation of solar modules into saw-tooth designs and awnings on a building facade. The angle of the awning increases access to direct sunlight, meaning increased energy. These can be used in entrances, terraces or simply as awnings to shade the rooms inside, protection from wind and rain. They also protect against lightning, being an electrical resistor,
- Usage of photovoltaics in a building envelope replaces traditional building materials and building processes. For example using BIPV in roofing systems may replace batten and seam metal roofing, and traditional 3-tab asphalt shingles,
- The glass-glass modules can be utilised as balustrades on balconies, for example for large rented accommodation or terraced houses, creating an eye-catching structure [17],
- Usage of solar modules as thermal insulation through the sandwich-construction of the modules themselves, the layer of air within the modules and the ray absorption by the crystalline silicon and thin film solar cells. This means that less energy is wasted by heat loss from the interior, reducing heating costs and keeping the building at an ambient temperature,
- Repelling of unwanted noise pollution and creation of a screen against potential electromagnetic interference, including so-called electro-smog. This makes them particularly useful in situations with large amounts of sensitive electrical activity, for example hospitals or airports [18].

Obviously, in the process of designing buildings with integrated photovoltaic systems one should comply with the same requirements that must be met by standard photovoltaic systems, concerning the exposure to sunlight and shading of the panels, and taking into account the position of the Sun relative to the panels during the year. At the current state of knowledge, BIPV appears to be one of best concepts for the acquisition of electric power from renewable sources, that should be implemented and actively developed in the future. This method of exposing the use of photovoltaics may have an effect on increasing the ecological awareness of the population and enhancing the level of acceptance for that form of power generation. With this method we can utilise all available and suitable surfaces of the walls and roofs of not only houses and apartment blocks, but also of industrial buildings or buildings devoted to farming and food production, making them more ecological and at the same time less dependent on the conventional suppliers of electric power.

SUPPORT SYSTEMS FOR PHOTOVOLTAICS

In Poland the development of photovoltaics is a very slow process mainly to the lack of suitable legislation that would provide detailed regulations concerning the conditions for connecting such systems to the power grid, or for the take-off and sale of energy produced in such systems. In other EU countries such regulations have been functioning for years, in conjunction with various support mechanisms aimed at increasing the level of utilisation of renewable energy sources. The best solution, applied e.g. in Germany and Japan, was the introduction of so-called Feed-in-tariff (FIT), i.e. state subsidies to each kWh of "clean" energy. Those subsidies proved to be the most effective mechanism of supporting the development of photovoltaics, and are now the foundation determining stable development of energy markets all over the world. Apart from FIT, other systems of support used in the world include tax incentives (Lithuania, Slovakia), guaranteed subsidies in the form of environmental payments, or investment subsidies that one can apply for prior to or in the course of realization of a project [19]. The only support system currently functioning in Poland is the system of so-called green certificates. For several years now there have been announcements of new legislation on renewable energy sources that is to replace the existing system. In the case of agricultural and food production there is also the possibility of taking advantage of EU subsidies for the development of agriculture, amounting even up to 75% of costs related with investments concerning the production of "clean" energy, available via the Agriculture Restructuring and Modernisation Agency [20].

CONCLUSIONS

Technologies utilising solar radiation for the production of electric energy have been in use for over 30 years. At present it is one of the fastest developing alternative methods of acquisition of electric power. Compared to conventional power generation plants, the use of photovoltaic systems has numerous advantages, such as:
- power source – the Sun (practically inexhaustible energy resources),
- no significant effect on climate change of generation of pollutants, e.g. exhaust fumes and gases,
- low operation costs of such installations,
- no moving parts (longer service life of systems),
- possibility of safe operation at high temperatures,
- high reliability of cells/panels (up to ca. 20 years of service life),
- fast assembly of installations,
- possibility of installations on existing structures,
- possibility of installation at almost every location and providing power supply for objects situated in inaccessible areas or in areas with poorly developed electric supply grid,
- high level of social acceptance,
- low failure rate.

The disadvantages of photovoltaic systems are the following:
- high cost of complete PV installations,
- sensitivity weather changes limiting the production of electric power,
- lack of an economically effective system of energy storage (the current generation batteries have not achieved a sufficient level of development in terms of service life and storage capacity).

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FOTOWOLTAIKA – TERAŹNIEJSZOŚĆ I PRZYSZŁOŚĆ

Streszczenie. W niniejszej pracy przedstawiono możliwości wytwarzania energii elektryczne za pomocą ogniw słonecznych, których działanie opiera się na absorpcji promieniowania widzialnego i efekcie fotowoltaicznym. Omówione zostały zalety i wady fotowoltaiki oraz przykłady zastosowania ogniw słonecznych w przemyśle i rolnictwie. Ze względu na wysokie koszty inwestycji rozwój fotowoltaiki wspiera się w wielu krajach świata poprzez systemy dopłat lub taryf stałych, co znacznie zwiększa jej atrakcyjność.

Słowa kluczowe: fotowoltaika, promieniowanie słoneczne, BIPV.