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OPTIMISING ENERGY PRODUCED BY PHOTOVOLTAIC CELLS

OPTYMALIZACJA POZYSKIWANIA ENERGII Z OGNIW FOTOWOLTAICZNYCH

A b s t r a c t

This paper presents a comparative analysis of energy produced by photovoltaic (PV) panels installed on fixed structures and on solar trackers. Measurements were taken continuously over a period of one year. Performance results for both one year and 24 hours are presented. Attention is also paid to current Polish and European legislation promoting the installation of systems that use energy from renewable sources.

Keywords: *photovoltaic*, *solar energy*, *PV modules*, *tracker*, *renewable energy*

S t r e s z c z e n i e

A artykule przedstawiono analizę porównawczą zysków energii z paneli fotowoltaicznych zamontowanych na konstrukcji stacjonarnej oraz na konstrukcji nadążnej, kierującej się w stronę słońca. Pomiary prowadzone były przez okres roku w trybie ciągłym. Przedstawiono analizę roczną oraz dobową. Zwrócono również uwagę na aktualne polskie i europejskie ustawodawstwo promujące budowę instalacji pozyskujących energię ze źródeł odnawialnych.

Słowa kluczowe: *fotowoltaika*, *energia słoneczna*, *ogniwa PV*, *system nadążny*, *energia odnawialna*

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1. Introduction

Directive 2009/28/EC [1] of the European Parliament and Council was passed in April 2009 and came into force on 25th June 2009. Its aim is to promote the use of energy from renewable sources and the target set out by the European Union is for renewable energy to make up 20% of total energy consumption by the year 2020. This target was translated into individual goals for the Member States, in Poland's case this has been set at 15.48%. According to Eurostat [2], the average EU consumption of renewable energy in 2012 was 14.1%, while in Poland it was 11% (Table 1).

Table 1

Share of renewable energy in gross final energy consumption [%]

	2005	2009	2010	2011	2012	Target
European Union (28 countries)	8.7	11.9	12.5	13.0	14.1	20
Poland	7.0	8.8	9.3	10.4	11.0	15.48

The support system for renewable energy production in Poland is included in the draft law on renewable energy sources. The recently published revision 6.2 of 4th February 2004 [7] contains provisions that regulate the connection of micro and small installations (up to 40 kW) to the national power grid. The user of such an installation will pay for the energy difference between the energy consumed from the grid and the energy transmitted into the grid, and the excess energy will be paid to the user at 80% of the energy price on the competitive market.

The European Commission Report of March 2013 [9] provides progress assessments of the Directive's [1] targets and performance forecast, with division into individual sources of renewable energy. The most promising development is seen in the solar energy sector. This is due to dynamic developments in technology, especially in photovoltaics. PV systems are easy to install, long-lasting and scalable, which allows their use both in household systems and in the construction of high power plants. The solutions proposed in the draft law on renewable energy sources allow the simplification of PV systems by eliminating the need for expensive batteries to store surplus energy.

Compared to southern European countries, Poland has nearly two times less solar radiation intensity, falling to three times lower when compared to areas on Earth that are most exposed to solar radiation (Fig. 1). It is therefore especially important that PV systems are designed to optimise any energy gain. The amount of solar energy absorbed is affected by the location of the system, inclination, possibly obstacles that shade the solar radiation, weather conditions and the solar cell temperature. Not all of these conditions are within our control. However, what we can control is the solar panel inclination angle, which can follow the movement of the sun (solar tracking system). The use of a solar tracking system provides significant improvements in energy efficiency, but also limits the number of locations where such systems can be installed. In a later part of the paper, analysis and results of measurements of energy produced by PV panels installed on a tracking system of the author's own design is presented (Fig. 4).

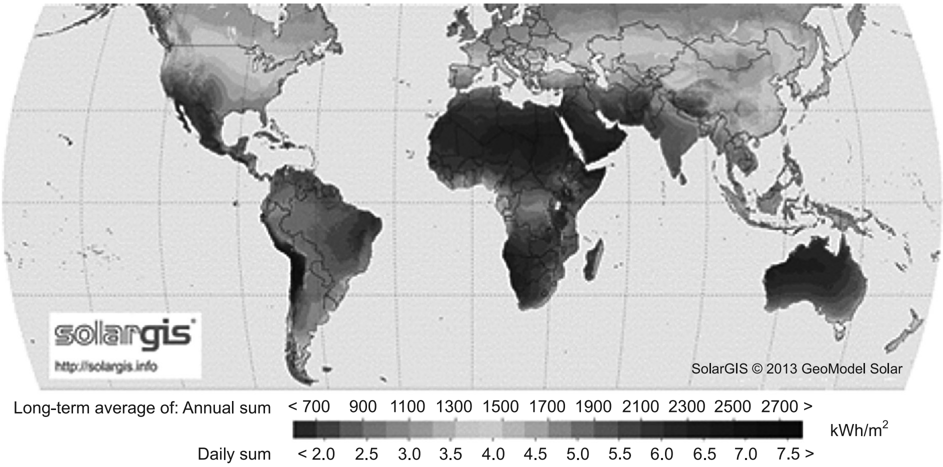

Fig. 1. World map of global horizontal irradiation [3]

2. Photovoltaic (PV)

The total solar energy reaching the Earth has a power of ca. 8×10^{10} MW. Average power consumption needs are estimated to be ca. 0.001×10^{10} MW. Solar energy is potentially an unlimited and an environmentally-friendly source of energy. The simplest way of producing solar energy is the use of photovoltaic (PV) panels. There has been very strong growth in this sector of the economy over the last dozen years or so. The European Photovoltaic Industry Association (EPIA) states that at least 37 GW of new PV systems [6] were installed in 2013. At the end of 2013, the world's power from installed PV systems was 136.7 GW [6], which gives about 0.4% of the world's total energy demand.

2.1. Photovoltaic effect

A solar cell operates according to the photovoltaic effect principle, which produces electromotive force as a result of radiation falling onto a photovoltaic semiconductor cell (Fig. 2). This effect was observed as early as the year 1839. The voltage and power produced by a single PV cell is low (about 0.5 V), therefore the cells are combined into modules, and these into panels.

With regard to the design of PV cells, several generations can be distinguished. Currently, the most popular are still the 1st generation cells based on crystalline silicon (mono or polycrystalline). The second generation cells (CdTe, CIGS) that are now being mass-produced are increasing their market share year on year. However, the biggest hope for the future is brought by the third generation cells (organic and Dye Sensitized Solar Cells – DSCC). DSCC solar cells generate electricity via the phenomenon of photosynthesis. Their design uses platinum, which makes production significantly more expensive. However, developments in recent years have allowed platinum to be replaced with cheap 3D structure graphene components [5].

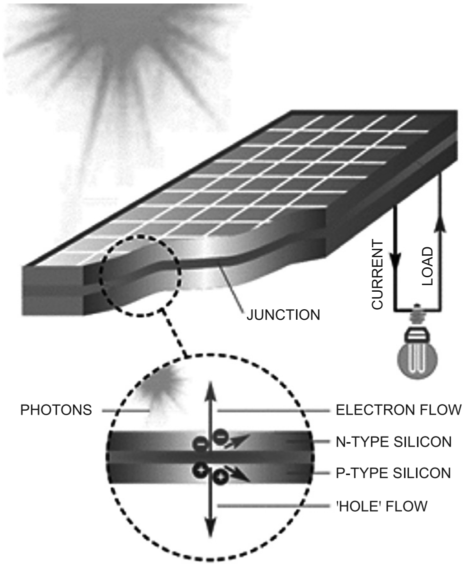

Fig. 2. Example of the photovoltaic effect [8]

2.2. PV Systems

PV systems can be divided according to location into free-standing, Building Adapted PV Systems (Building Adapted PV Systems – BAPV) and Building Integrated PV Systems (Building Integrated PV Systems – BIPV). In terms of connection with the power grid, PV systems are divided into those connected to the grid (on-grid systems) and those not connected to the grid (off-grid systems). The latter type is used in areas where the power grid is not available, and in Europe, these are rare. A typical on-grid system diagram is shown in Fig. 3. The PV panels generate direct current (DC). The direct current (DC) is converted into alternating current (AC) using inverters, which allows the power to be used to supply

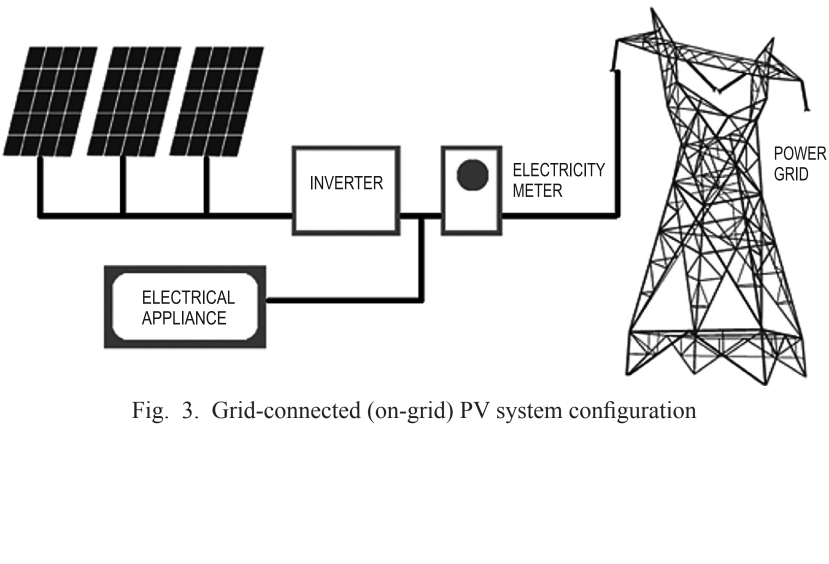

Fig. 3. Grid-connected (on-grid) PV system configuration

the site loads. When there is a surplus of energy, it can be transferred to the power grid through a bi-directional power meter. In the case of insufficient power produced by the PV panels, power is taken from the grid. The solar energy producer pays or receives payment, according to the balance of energy consumed and supplied to the grid.

2.3. PV panel support structures

The PV panels are installed on support structures. In Poland, all panels should be directed south. The inclination angle should be about 25 degrees in summer and about 60 degrees in winter. The universal angle used in fixed installations (without inclination angle adjustment) is assumed at 33-38 degrees. A free standing PV installation can use a solar tracker system, which follows the movement of sun to keep the panel perpendicular to the sun's rays. The best performance is achieved using double axis tracking systems. Such systems can be controlled based on the calculated position of the sun or on measurement of radiation.

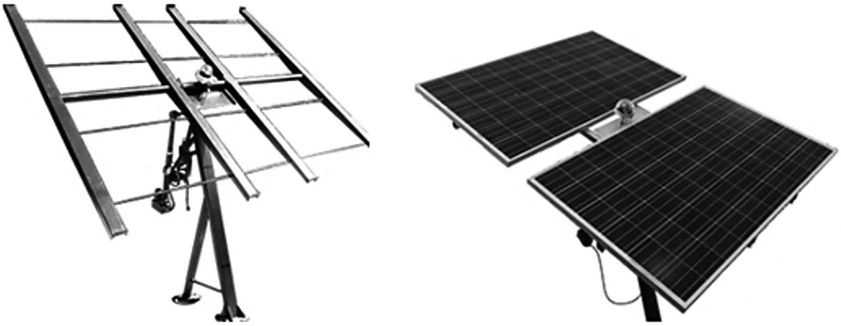

Fig. 4. Double axis solar tracking systems

The proprietary solution uses a double axis system (Fig. 4) with an infrared sensor. The IR sensor allows the system to operate even on cloudy days. The system features a very wide range of movement. In the east-west line, the maximum angle of movement is 238 degrees, while in the north-south line, it is 85 degrees.

3. Optimising the PV cell output

The amount of energy produced by the photovoltaic cell depends on the efficiency of the cell and the intensity of radiation. The efficiency of solar cells currently manufactured by industry is 15–18%. This solar cell efficiency is also affected by its operating temperature – the higher the temperature, the lower the efficiency. At a temperature of 80 degrees, which can be achieved in summer, the efficiency drop is about 25%. To eliminate the reduction of cell efficiency in summer, it should be provided with appropriate ventilation or cooling. Also, the PV surface should be kept clean, especially in dry seasons. Even a small stain caused by bird droppings, can lower the PV efficiency by as much as 33% [10]. The highest intensity of solar radiation is when the sunrays' incidence is perpendicular to the PV surface. Only the use of solar tracking systems ensures optimum energy output.

3.1. The intensity of the solar radiation

The intensity of the solar radiation reaching the upper limit of the Earth's atmosphere is described by the solar constant. This value is defined for the average Earth-Sun distance and it is about 1366.1 W/m^2. About 50% of this radiation reaches the Earth's surface, and the remaining part is reflected or absorbed by the atmosphere. The actual intensity of solar radiation depends on the geographical position of the measurement point and the transparency of the atmosphere. The highest intensity occurs within the equatorial zone, and decreases

Fig. 5. Global horizontal irradiation. Poland [4]

with the distance from the equator. Poland is located within the moderate radiation zone with solar radiation intensity nearly 3 times lower than in the most insolated regions of the Earth (Fig. 1). In Poland (Fig. 5), the assumed yearly energy gain from a horizontal plane is from 900 to 1200 kWh/m^2, depending on location. The solar radiation that reaches the Earth's surface can be divided into direct and dispersed. Poland is characterised by a high portion of dispersed radiation, which is estimated at 47% in summer, and up to 77% in winter. About 80% of the yearly total radiation occurs during the six months of the spring and summer seasons.

3.2. Analysis of energy gains using the solar tracking system

The installed proprietary solar tracking system allows tracking of the solar rays within the full range of angles. The system is controlled using infrared sensor measurement. This allows the system to be directed towards the sun even during cloudy weather.

Measurements were carried out during the period from March 2013 to February 2014 to determine the power output from PV panels installed in a solar tracker and in a fixed system directed to the south at an angle of 36 degrees. Each system contained two PV panels

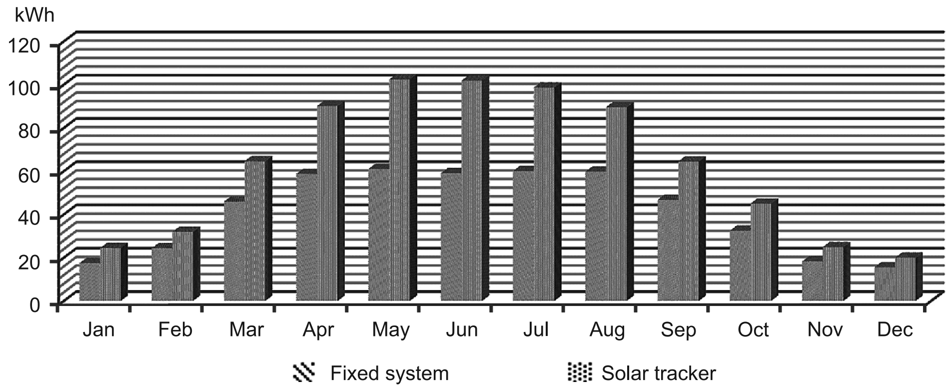

Fig. 6. Average monthly electricity production from the given system (kWh)

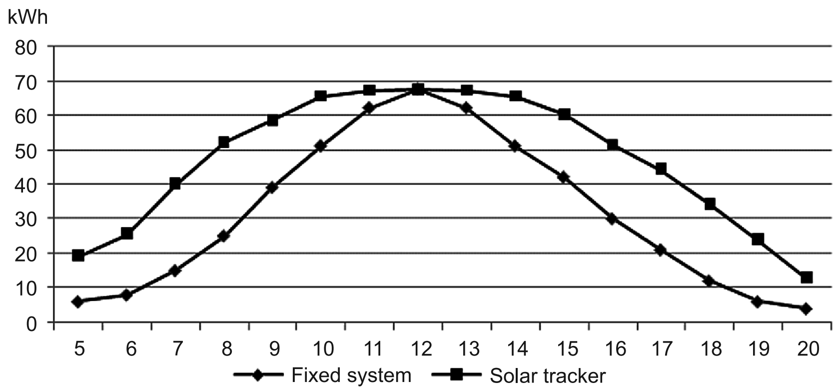

Fig. 7. Average daily electricity production from the given system (kWh)

of total power 510W, according to the manufacturer's specification. Measurements were carried out continuously, from sunrise to sunset. The goal of the analysis was to determine the difference between the energy outputs of the solar tracking system and the fixed system. Results of the analysis for periods of 24h (Fig. 7) and the entire year (Fig. 6), are given in the attached charts.

4. Conclusions

The study shows that the monthly average energy output improvement achieved by the use of the solar tracker compared to the fixed system ranges from 28% in winter to 72% in summer. During the morning and evening hours, the fixed system operates at a very unfavorable angle. Such a high difference during the summer season is a result of the increased amount of daylight – when the daylight period is longer, the solar tracker operates more efficiently than the fixed system. The difference over the whole year is 52% more energy obtained from the solar tracker. If you add the benefits of proper system maintenance (good ventilation, surface cleaning, clearing of snow) the system efficiency can be up to two times higher. This shortens the time required for return on investment.

Solar tracking system design idea: Paweł Gałek, Gwalbert Stefański
System implementation: F.H.U. Bartek

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