# The influence of external conditions and orientation of PV module on the energetic gain

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Paper presents the influence of external conditions such as: the latitude φ, the solar declination δ, the hour angle ω, number of sunny hours, cloud cover and orientation of photovoltaic module on the energetic gain. The results of the measurements of radiation power density that reaches the surface of the PV receiver for its different positions, for the geographic location of the cities of Poznań and Playa del Ingles and for different time periods (yearly and daily) are presented in a graphical form. The study compares also production of electric power and energy in different weather conditions: cloudy, partly cloudy and cloudless sky using two-axis tracking system and fixed with one optimal angle setting during the year. Analyzed systems are located in Poznan on the roof of the Faculty of Electrical Engineering building. Distribution of power density of solar radiation in different days of the year was also compared.

KEYWORDS: photovoltaic conversion, double - axis tracker, energetic gain, external conditions

## 1. Introduction

The insolation conditions on the territory of Poland (49°-54,5°N) are similar to analogous conditions in most European countries [1, 2, 4, 5, 6]. The yearly illuminance value per unit area for most of the Polish territory can be estimated to amount to over 1000 kWh/m$^2$ (950 -1250 kWh/m$^2$). Coastal areas, including Gdańsk - 1117 kWh/m$^2$ and Szczecin - 1137 kWh/m,$^2$ are characterized with the most advantageous conditions in that respect. In central Poland and in the south, illuminance values are not much lower: Warsaw - 1022 kWh/m$^2$, Poznan - 1011 kWh/m$^2$, Katowice - 1053 kWh/m$^2$, Krakow – 1052 kWh/m$^2$. Yearly amount of solar radiation energy per 1 m$^2$ obtained in cities located in analogical latitudes is: 1150kWh/m$^2$ in Munich and 1000 kWh/m$^2$ in Berlin. This means that an installation of 1kWp can collect about 900-950 kWh of electric power in optimal working conditions. Average monthly insolation for selected cities within the country is presented in Table 1.

The annual distribution of solar radiation is characterized with irregularity. Spring and summer constitute over 75% of annual potential.

The basic value describing resources of solar radiation is sunshine duration. It is also the first value that was measured and included in the terminology concerning solar energy. Sunshine hours are measured by means of a heliograph which features a crystal ball that performs the function of a lens focusing sun rays on special stripes of paper. Their length and position depend on the time of the year: the longest and lowest stripe in summer time, medium stripe in spring and autumn months and the shortest and highest stripe in winter time. The sun rays burn a mark whose length denotes Sun exposure time with an accuracy of 0,1 h [15].

The number of sunny hours reaches 1600 hours per year [7]. The number of solar activity hours on different days of the year fluctuates from 8 to 16. The fluctuation in the number of sunny hours applies also to different regions of the country which results from the impact of the latitude angle. For example, the insolation value for Kołobrzeg is 1624 hours per year, whereas for Zakopane the value is only 1467 hours per year.

Table 1. The average monthly amount of solar energy for a perpendicular plane for selected cities in Poland [12]

| City/Month | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| Gdańsk | 20,5 | 36,9 | 78,1 | 125,1 | 180,1 | 173,1 |
| Warsaw | 26,9 | 45,4 | 78,7 | 109,5 | 155,3 | 146,1 |
| Szczecin | 20,5 | 37,8 | 83,1 | 126,6 | 183,5 | 173,4 |
| Kraków | 29,1 | 47,6 | 82,2 | 111,3 | 150,7 | 145,8 |
| City / Month | VII | VIII | IX | X | XI | XII |
| Gdańsk | 177,1 | 137,7 | 94 | 54,3 | 25,7 | 15 |
| Warsaw | 151,9 | 128 | 85 | 51,9 | 28,5 | 19,8 |
| Szczecin | 177,6 | 137,4 | 100,5 | 56,1 | 25,73 | 15,30 |
| Kraków | 157,5 | 131,2 | 89,9 | 56,7 | 29,8 | 21 |
| Rzeszów | 157,8 | 133,2 | 89,9 | 55,8 | 29,1 | 21,3 |
| Average monthly insolation kWh/m2/month | | | | | | |

Unfortunately, the share of the diffuse radiation element in the total radiation value is high, 50% on average, and even over 70% in winter [7].

Thus, the availability of solar resources is influenced by a number of external factors, such as the geographic location, time factors (within the period of a day and of a year), cloud cover, the number of sunny hours [3, 4, 8]. To sum up, it is, however, found that the solar energy potential in our country provides a lot of capabilities but requires appropriate utilization as well as neutralization of the disadvantageous external factors.

Determining the angle at which the sun rays fall on the surface of the receiver that guarantees maximal energy gains, but which is a function of many variables, is helpful in this context [1]:

$$\cos\Theta_{\beta} = \sin\delta\sin\varphi\sin\beta - \sin\delta\cos\varphi\sin\beta\cos\gamma + \\ + \cos\delta\cos\varphi\cos\beta\cos\omega + \cos\delta\sin\varphi\sin\beta\cos\gamma\cos\omega + \\ + \cos\delta\sin\beta\sin\gamma\sin\omega$$

where: φ-latitude angle, δ-solar declination angle, γ-receiver azimuth, that is the deflection angle with the local meridian measured in relation to the south, negative to the east, positive to the west, ω-hour angle, β-the inclination angle of the recipient in relation to the horizon.

Change of value of the inclination angle β and the azimuth angle γ allows to optimize the energy gain thanks to periodic reorientation of the photovoltaic module's surface. This situation has been demonstrated through theoretical discussions by the authors and has been complemented by a computer simulation which, on the basis of defined time parameters such as the day of the year and the hour of the day, ground reflexivity index as well as contributory values of direct, diffused and reflected sun radiation, has established values of radiation density for defined spatial settings of the PV receiver. A variation waveform of corrective indices for the direct contributory value $R_b$ and diffusive contributory value $R_d$ has also been drawn up. This was proved through theoretical considerations complemented with a computer simulation [1].

## 2. The influence of the latitude angle on radiation power density

As it was demonstrated in [1, 8], the latitude angle has a considerable influence on the possibility of using solar energy. The awareness of this phenomenon will make it possible to use the positioning of the receiver in order to minimize the negative effects for the energy gain.

Table 2 presents examples of solar energy potential for a receiver positioned horizontally in selected geographic locations.

Table 2. Comparison of solar conditions for different locations [3]

| City | Geographic location | | | Total radiation [MJ/m²/year] | Number of sunny hours [h] |
|---|---|---|---|---|---|
| | Latitude | Longitude | AMSL height | | |
| Helsinki | 60° 19' N | 24° 58' E | 48 | 3495 | 1740 |
| St. Petersburg | 59° 18' N | 30° 18' E | 72 | 3369 | 1700 |
| Stockholm | 59° 21' N | 18° 04' E | 30 | 3479 | 1700 |
| Kaunas | 54° 53' N | 23° 53' E | 73 | 3744 | 1700 |
| Gdynia | 54° 31' N | 18° 33' E | 22 | 3667 | 1624 |
| Kołobrzeg | 54° 11' N | 15° 35' E | 16 | 3830 | 1618 |
| Suwałki | 54° 06' N | 22° 57' E | 193 | 3525 | 1577 |
| Mikołajki | 53° 47' N | 21° 35' E | 127 | 3636 | 1598 |
| Hamburg | 53° 39' N | 10° 07' E | 49 | 3421 | 1533 |
| Potsdam | 52° 23' N | 13° 06' E | 110 | 3643 | 1677 |
| Warsaw | 52° 16' N | 20° 59' E | 130 | 3477 | 1600 |
| London | 51° 31' N | 0° 07' W | 77 | 3402 | 1530 |
| Kiev | 50° 24' N | 30° 27' E | 121 | 4230 | 1877 |
| Zakopane | 49° 18' N | 19° 57' E | 857 | 3556 | 1464 |
| Paris | 48° 49' N | 2° 30' E | 50 | 4068 | 1658 |
| Vienna | 48° 15' N | 16° 22' E | 202 | 3881 | 1716 |
| Budapest | 47° 26' N | 19° 11' E | 130 | 4320 | 1830 |
| Rome | 41° 48' N | 12° 35' E | 131 | 4968 | 2445 |

Level of the registered solar radiation intensity is closely dependent on the angle of the local latitude at the place where the measured value is read. Decreasing the value of angle φ for equatorial areas significantly improves the insolation time as well as the Sun exposure time. Table 3 shows minimum and maximum daily amounts of solar radiation intensity as well as a yearly value including the total amount of direct and diffused radiation.

Table 3. Values of daily and yearly solar radiation intensity (insolation) for extreme latitude angles [15]

| Location | Latitude | Max. insolation | Min. insolation | Yearly total |
|---|---|---|---|---|
| Equator | 0 | 6.5 (7.5) | 5.8 (6.8) | 2200 (2300) |
| Tropic of Cancer | 23.5 | 7.1 (8.3) | 3.4 (4.2) | 1900 (2300) |
| Average location | 45 | 7.2 (8.5) | 1.2 (1.7) | 1500 (1900) |
| Central Poland | 52 | 7.0 (8.4) | 0.5 (0.8) | 1400 (1700) |
| Polar region | 66.5 | 6.5 (7.9) | 0 (0) | 1200 (1400) |
| Insolation value in kWh/m2 | | | | |

In order to confirm the theoretical considerations and the results of the computer simulation [1] regarding the influence of the latitude on the availability of solar energy, the authors conducted measurements of the values of radiation power density for two different geographic locations: in Poznań (Poland) 52°24'30"N, 16°56'3"E and for Playa del Ingles (Gran Canaria, Spain), 27°45'24"N and 15°34'43"W, Fig.1 [9]. The measurements were performed in the same time periods, days and hours, and for the same positioning.

Figures 2 and 3 present the radiation power density values obtained from the measurements, for example for the day of 6.08.2012, 18:00, taking into account the spatial optimization of the receiver with respect to the receiver inclination angle in relation to the horizon and the azimuth angle for the geographic locations analyzed, according to Fig. 1.


Fig. 1. Geographic location of the cities analyzed, included in the measurements of illuminance values

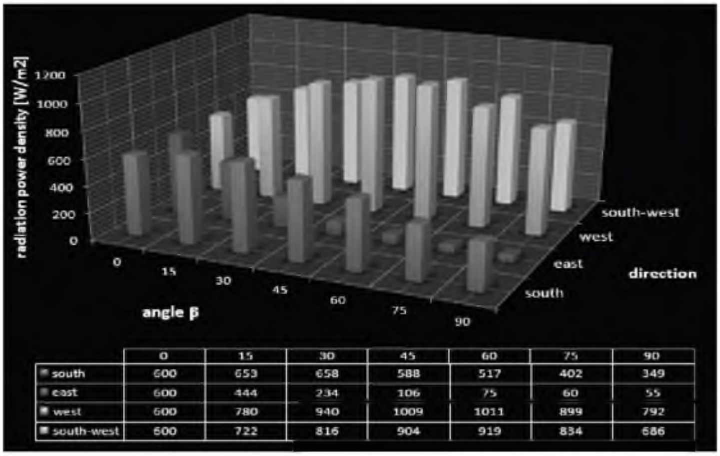


Fig. 2. Radiation power density as a function of the positioning angles for Playa del Ingles on 6.08.2012 at 18.00, on the basis of own measurements

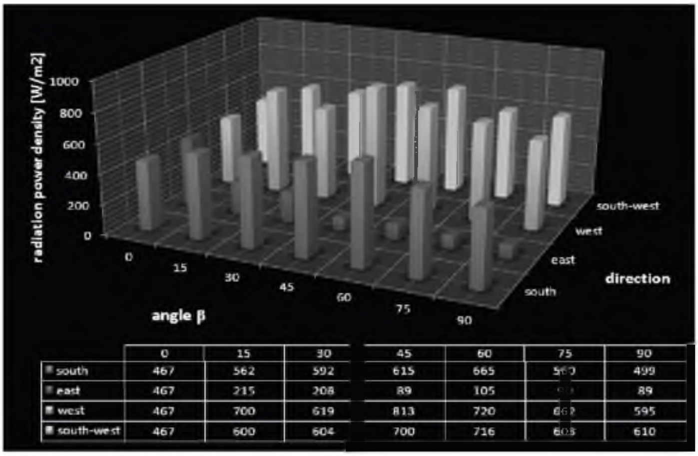


Fig. 3. Radiation power density as a function of the positioning angles in Poznań (Poland) on 6.08.2012 at 18.00, on the basis of own measurements

The authors have also performed a computer simulation of a yearly gain of electric power by means of Microsoft Visual C# programming environment and PV-Sol software. The simulation featured photovoltaic modules of maximum power of 1000 Wp installed at a defined inclination angle $\beta = 30°$ and an azimuth angle of 0°. The variable parameter in the calculation is the angle of the local latitude. In this way, the authors have established how the $\varphi$ angle parameter influences the predicted gain of electric power coming from solar energy. The subject of the study is shown in Fig. 4. The results of the simulation for selected latitudes are presented in Table 4.

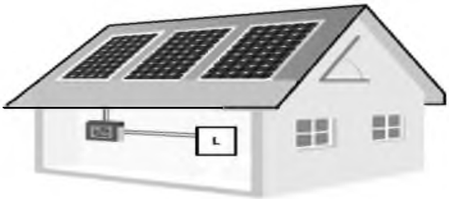

Fig. 4. Single-family house with photovoltaic modules installed at a constant angle of inclination and azimuth (β, γ = const) , φ = var

Table 4. Comparison of annual electrical energy gain from 1kWp installed for equal spatial orientation of the PV modules

| No. | Country | City | Latitude | Longitude | Annual energy gain [kWh/year/1kWp] |
|---|---|---|---|---|---|
| 1 | Brazil | Porto Alegue | 30°02' S | 51°18'W | 926 |
| 2 | Canada | Toronto | 43°41'N | 79°28E | 1239 |
| 3 | Chile | Santiago | 33°27'S | 70°40'W | 996 |
| 4 | Egypt | Aswan | 24°05'N | 32°56'E | 1873 |
| 5 | Germany | Berlin | 52°31'N | 13°24'E | 926 |
| 6 | Greece | Saloniki | 40°38'N | 22°57'E | 1188 |
| 7 | Italy | Rome | 41°53'N | 12°29'E | 1442 |
| 8 | Norway | Oslo | 59°54'N | 10°44'E | 967 |
| 9 | Spain | Barcelona | 41°23'N | 2°10'E | 1298 |
| 10 | Poland | Poznan | 52°24'N | 16°56'E | 982 |
| 11 | Spain (Gran Canaria) | Playa del Ingles | 27°45"N | 15°34'W | 1645 |

## 3. The influence of the solar declination angle on radiation power density

The solar declination angle specifies the angular position of the Sun at astronomical noon time in relation to the plane of the equator. It is determined by the consecutive number of the day of the year. Thus, it is a variable value [4, 8]. Table 5 presents a summary of sample values of momentary power registered by the insolation sensor in one of the Silesian cities [12].

Table 5. Radiation power density values of the solar radiation falling on the horizontal plane in the cities of the Silesian Voivodeship in particular days and moments in time [12]

| Date/Hour | 3.07.2009 | 12.07.2009 | 17.08.2009 | 20.09.2009 |
|---|---|---|---|---|
| 10:00 | 907 W | 323 W | 587 W | 522 W |
| 12:00 | 1209 W | 1256 W | 1005 W | 1063 W |
| 18:00 | 136 W | 147 W | 140 W | 62 W |

The authors conducted radiation power density measurements for locations that are equivalent to the geographic location of the city of Poznań in different seasons of the year (the declination angle) and at different hours of the day (the hour angle). The measurements were started in the period in which it is possible to obtain high illuminance values, that is – in May; they were continued in summer months as well as in autumn and winter months. This made it possible to perform a comparative analysis of the available solar energy potential in the analyzed periods of time.

Sample results from the measurements performed on the horizontal plane for the selected days of 25.05., 9.07., 11.09., 1.10., 2012 and for 30.01.2013 and hours are presented on Fig. 5.

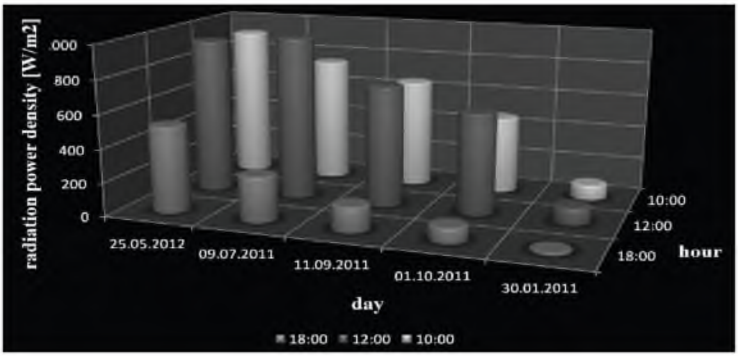


Fig. 5. Radiation power density values for the city of Poznań on the horizontal plane on specific days and at specific moments in time on the basis of own measurements

Figures 6 and 7 present the distribution of radiation power density per one second for different positions of the PV receiver for two selected days: 25 May and 25 July 2012 measured at 13:00.

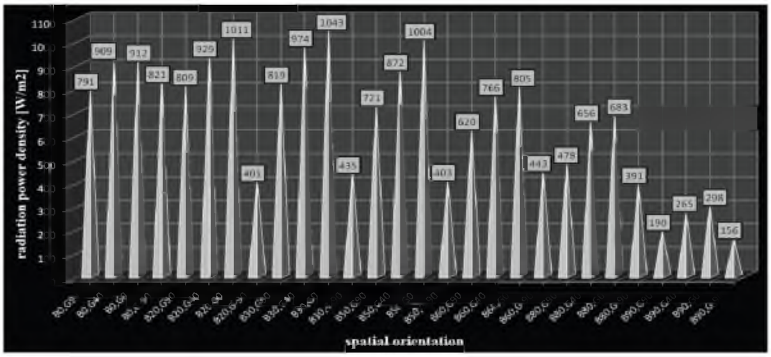


Fig. 6. The distribution of radiation power density per one second for different positions of the PV receiver with respect to the receiver inclination angle β to the horizontal and the azimuth angle γ, for 25 May 2012 (13.00), on the basis of own measurements

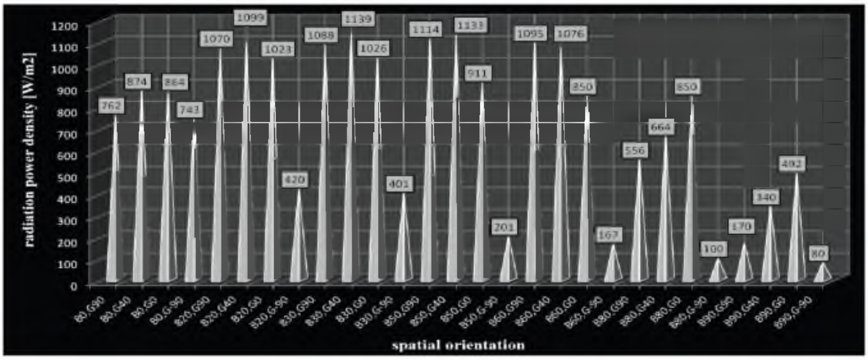


Fig. 7. The distribution of radiation power density per one second for different positions of the PV receiver with respect to the receiver inclination angle β to the horizontal and the azimuth angle γ, for 25 July 2012 (13.00), on the basis of own measurements

The influence of the Sun's declination angle on the availability of solar radiation power density has been confirmed by studies conducted on a special measurement station consisting of a two-axis follow-up system and a stationary system. Both units featured a photovoltaic module of maximum power of 210 Wp and a solar radiation power density detector operating together with an LB-900 microprocessor unit. A comparison of power value for a unit of surface on various days was conducted and in this way variability of power values on different days of the year was established. This, in turn, confirmed the influence of the δ angle on the availability of solar energy. View of the measurement station is shown in Fig. 8.

Fig. 8. View of measurement stand to determine the annual distribution of power density of solar radiation, taking into account changes in the spatial orientation of the receiver PV

Recorded values of solar radiation power density for different days of the year, affecting the solar declination angle are shown in Fig. 9.

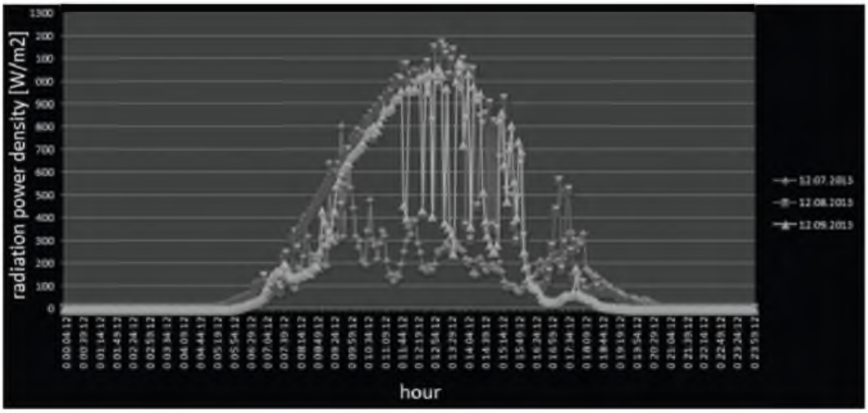


Fig. 9. Daily distribution of solar radiation power density for the twelfth day of the month in July, August and September for the stationary unit (β = 37°, γ = 0°)

## 4. The influence of the hour angle on radiation power density

The hour angle is an astronomical coordinate in the equatorial system and it specifies the angular declination of the sunrise or sunset in relation to the local meridian [8]. It is calculated from the south to the west and 1 hour corresponds with 15 degrees. It equals zero for 12.00. In the morning, the time change of an hour in relation to 12.00 corresponds with a change of the angle by -15°. In the afternoon, on the other hand, the time change of an hour corresponds with a change of the angle ω by +15°. Table 6 presents a comparison of the values of momentary power in specific hours of the day for the territory of Silesia on 3.07.2009 [12].

Table 6. Momentary power of insolation for the territory of Silesia on the horizontal plane as a function of the hours of the day on 03.07.2009

| Hour | Momentary power [W] |
|---|---|
| 8:00 | 132 |
| 9:00 | 291 |
| 10:00 | 907 |
| 11:00 | 875 |
| 12:00 | 1209 |
| 13:00 | 1301 |
| 14:00 | 1141 |
| 15:00 | 840 |
| 16:00 | 590 |
| 17:00 | 330 |
| 18:00 | 136 |
| 19:00 | 100 |
| 20:00 | 45 |
| 21:00 | 3 |

The study that featured the photovoltaic system became the basis for comparative measurements of distribution of the solar radiation power density for the stationary as well as the two-axis follow-up systems in a full hour range. Table 7 compares the values of solar radiation power density at given hours for the city of Poznan on 3 July 2013.

Table 7. Momentary power of solar radiation for the city of Poznan on a plane inclined at an angle of elevation β = 37 ° and tracking as a function of hours of the day 03.07.2012

| Hour | Momentary power Stacjo [W] | Momentary power Track [W] |
|---|---|---|
| 8:00 | 374,2 | 741,5 |
| 9:00 | 550,3 | 911,8 |
| 10:00 | 463,4 | 556,9 |
| 11:00 | 942,3 | 1058,8 |
| 12:00 | 1105,6 | 1121,7 |
| 13:00 | 1335,7 | 1329 |
| 14:00 | 1112 | 1100,8 |
| 15:00 | 229,4 | 262 |
| 16:00 | 857,1 | 998,8 |
| 17:00 | 712,6 | 1020,4 |
| 18:00 | 292,8 | 435,6 |
| 19:00 | 196,7 | 551,6 |
| 20:00 | 49,3 | 99,4 |
| 21:00 | 9 | 13 |

Figure 10 shows the distribution of radiation power density for different spatial settings of PV receiver depending on the work configuration.

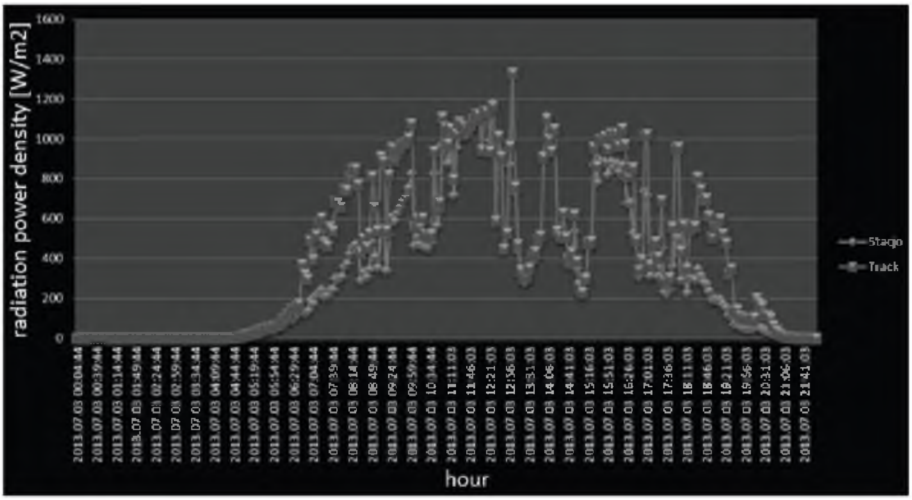


Fig.10. Radiation power density for a fixed and traking unit, 03.07.2013

## 5. The number of sunny hours

A parameter that characterizes the possibility of using solar energy is the period of time for which it is available during the day, that is the number of sunny hours with the luminous energy density ≥ 120 W/m$^2$ [5, 7]. In our climate, this is not synonymous with the number of day hours (from the sunrise to the sunset). The countries that are located in low latitude areas are characterized with a shorter day but with a dominant number of sunny hours and that is why the ratio of sunny hours to the number of day hours is higher in those areas than in Central European climate with relatively infrequent periods of cloudy weather. In connection with the clear dominance of the direct radiation element in solar radiation, the insolation in those areas is much higher than in Poland.

The device used for the measurement of insolation is a Campbell-Stockes heliograph. Its main element performing the function of a focusing lens is a crystal ball that refracts solar radiation in accordance with the defined refractive index. Placement of the ball in a special holder and maintaining the required distance from its case allows to insert a chalk-covered paper stripe featuring a time scale. Radiation that is focused on the stripe burns a mark whose length is proportional to the Sun exposure time. What becomes important, is a proper orientation of the device against the directions of the world, setting the latitude of the observation spot and ensuring a free access of solar radiation without shading.
Cut-outs located on the device's case allow to use the stripes that are appropriate for the current measurement season: long stripes for summer time, medium stripes for spring and autumn, as well as short stripes for winter time. The device is able to record sun rays that generate power higher than 209 W/m2 which limits the measurement during morning hours and just before sunset [15].

Table 8 presents a summary of the average number of sunny hours in the winter period (January), table 9 in June and table 10, respectively, in the summer period (August), measured in the Ławica airport [14].

Table 8. The number of sunny hours during the day (insolation) in January in the years 2000-2011 [14]

| Year | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|
| [hours] | 4.3 | 2.5 | 3.5 | 2.4 |
| Availability [%] | 32 | 54 | 51 | 45 |
| Year | 2004 | 2005 | 2006 | 2007 |
| [hours] | 2.2 | 2.7 | 3.4 | 1.9 |
| Availability [%] | 51 | 61 | 48 | 67 |
| Year | 2008 | 2009 | 2010 | 2011 |
| [hours] | 2.9 | 3.4 | 3.4 | 2.0 |
| Availability [%] | 58 | 41 | 32 | 32 |

The averaged value for January ( 2000 - 2011) is 2.9 hours.

Table 9. The number of sunny hours during the day (insolation) in June in the years 2000-2011 [14]

| | | | | |
|---|---|---|---|---|
| Year | 2000 | 2001 | 2002 | 2003 |
| [hours] | 9.4 | 6.4 | 8.7 | 11.4 |
| Availability [%] | 100 | 93 | 93 | 90 |
| Year | 2004 | 2005 | 2006 | 2007 |
| [hours] | 7.8 | 9.7 | 10.0 | 8.9 |
| Availability [%] | 100 | 96 | 100 | 90 |
| Year | 2008 | 2009 | 2010 | 2011 |
| [hours] | 11.3 | 6.7 | 10.8 | 10.3 |
| Availability [%] | 96 | 96 | 93 | 96 |

The averaged value for June ( 2000 - 2011) is 9.3 hours.

Table 10. The number of sunny hours during the day (insolation) in August in the years 2000-2011 [14]

| | | | | |
|---|---|---|---|---|
| Year | 2000 | 2001 | 2002 | 2003 |
| [hours] | 8.6 | 8,2 | 8,2 | 9,0 |
| Availability [%] | 100 | 96 | 96 | 93 |
| Year | 2004 | 2005 | 2006 | 2007 |
| [hours] | 8,1 | 9,4 | 6,8 | 8,2 |
| Availability [%] | 96 | 87 | 80 | 100 |
| Year | 2008 | 2009 | 2010 | 2011 |
| [hours] | 7,4 | 10,7 | 7,3 | 8,4 |
| Availability [%] | 90 | 93 | 93 | 100 |

The averaged value for August ( 2000 - 2011) is 8.4 hours.

The number of sunny hours during the day (insolation) in January, June and in August in the years 2000-2011 with polynomial approximation are presented (Fig. 11).

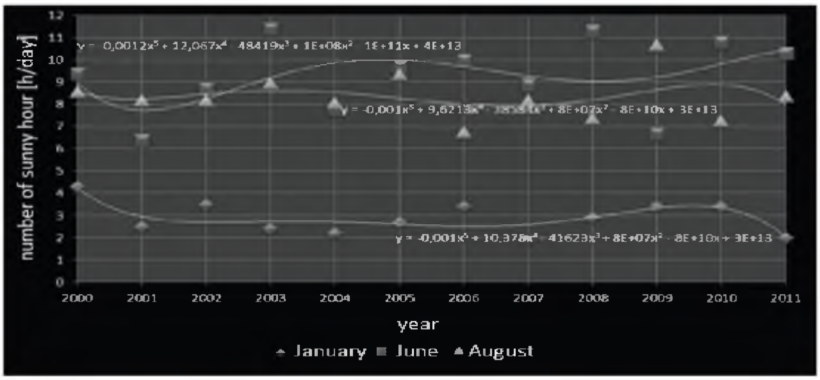


Fig. 11. The number of sunny hours during the day (insolation) in January, June and August in the years 2000-2011 with approximating polynomial

Table 11 presents the number of sunny hours during the day for particular months in Gran Canaria [13].

Table 11. The average number of sunny hours per day for particular months in Gran Canaria

| Month | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gran Canaria | 6 | 6 | 7 | 9 | 9 | 8 | 10 | 8 | 9 | no data | no data | no data |

## 6. Cloud cover

The characteristic features of the cloud cover in Poland include its variability in time throughout the year and relative stability for a given location. It is estimated that the cloudiest conditions exist in the north-east part of the country and the lowest level of averaged cloud cover per year can be observed in the south-west part of Poland. The remaining territory of the country demonstrates a certain level of monotony with that respect.

On the basis of meteorological data it can be stated that the period characterized by the highest amount of cloud cover are winter months, from November to January. During this period, the amount of cloud cover in Poland is higher than in Austria or Hungary; however, it is considerably lower than in Russia. On the basis of many years of analysis of the data available, it was found [11], that the minimal cloud cover can be observed in May, July, and August.

The lower the latitude towards the equator, the lower the cloud cover level. On average, about 140 days a year can be described as cloudy and 40 days can be described as "bright". The remaining days are periods of average, temporarily variable cloud cover [10]. Table 12 shows the annual degree of cloudiness of the country for selected regions including three types denoting cloudiness intensity: type 1 – 20% or less, type 2 – 21-79% and type 3 – full cloudiness of 80% and more.

On the basis of own measurements of illuminance distribution, it was found that the highest level of cloud cover occurs round noon. The phenomenon occurred cyclically throughout the whole multi-day measurement task.

Figure 12 presents the results of measurements of PV module characteristics for horizontal positioning on selected days in May 2012 for a cloudless sky and for considerably cloudy conditions.

For selected days of the year the authors have also assessed the influence of the degree of cloudiness on the amount of electric energy produced by the stationary system consisting of a polycrystalline photovoltaic module operating in the $\beta,\gamma$ angle configuration of 37°, 0° respectively, as well as a two-axis follow-up system of the same maximum power. Both systems featured LB-900 solar radiation power density detectors consisting of a silicon diode and a microprocessor system with a non-volatile memory that stores calibration data acquired in the course of the calibration process.

Table 12. Individual cloudiness types per 1 year within selected geographical areas of Poland [10]

| No. | region | Type 1 | Type 2 | Type 3 |
|---|---|---|---|---|
| 1 | seaside, western | 37.3 | 211.2 | 115.7 |
| 2 | seaside, central | 21.5 | 202.7 | 128.8 |
| 3 | seaside, eastern | 40.2 | 203.3 | 120.7 |
| 4 | Western Pomerania | 37.9 | 203 | 123.6 |
| 5 | Central Pomerania | 36 | 196.2 | 132 |
| 6 | Eastern Pomerania | 33.6 | 193.6 | 136.6 |
| 7 | Lower Warta river | 36.7 | 200.8 | 126.9 |
| 8 | Lower Vistula river | 35.6 | 200.1 | 128.2 |
| 9 | Lubusz area | 37.3 | 201.5 | 125.3 |
| 10 | Central Poland | 41 | 199.1 | 124.5 |
| 11 | Central Masovian | 38.2 | 204.5 | 121.5 |
| 12 | Torun area | 37.5 | 198.6 | 129.2 |
| 13 | Central Greater Poland | 39.1 | 205 | 120.2 |
| 14 | Cracov area | 41.9 | 192.5 | 130.6 |
| 15 | Rzeszów area | 45.7 | 197.3 | 121.5 |
| 16 | Sandomierz area | 53.1 | 196.9 | 114.3 |
| 17 | Zamość area | 53.3 | 198.1 | 113.1 |
| 18 | Podlasie | 35.5 | 198.5 | 127.1 |

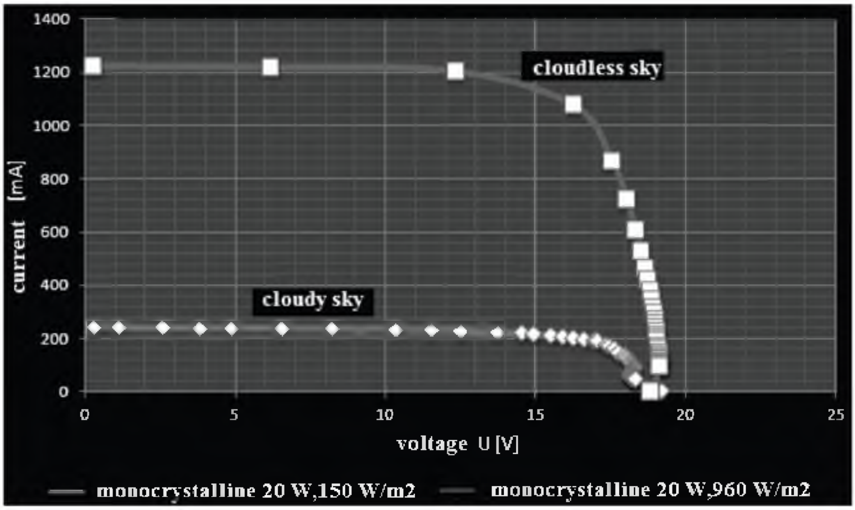


Fig. 12. The current and tensive characteristics of a monocrystalline USL 20 W module for cloudless and cloudy conditions

Fig. 13, 14, 15 show the daily production of electric energy by both component units of the PV system.

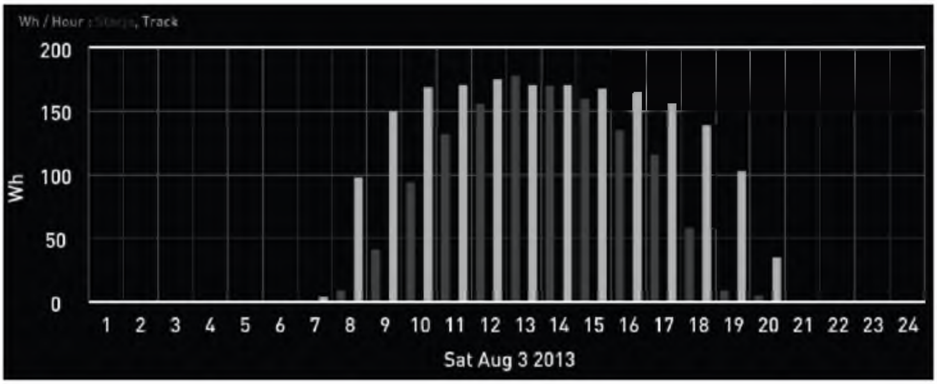


Fig. 13. Electrical energy generated by the tracking unit (Track) and fixed (Stacjo) per day, 03.08.2013, cloudless sky

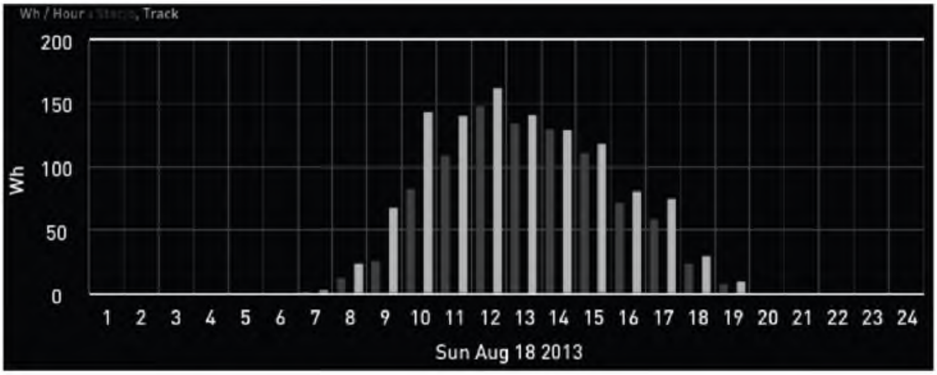


Fig. 14. Electrical energy generated by the tracking unit (Track) and fixed (Stacjo) per day, 18.08.2013, partly cloudy sky

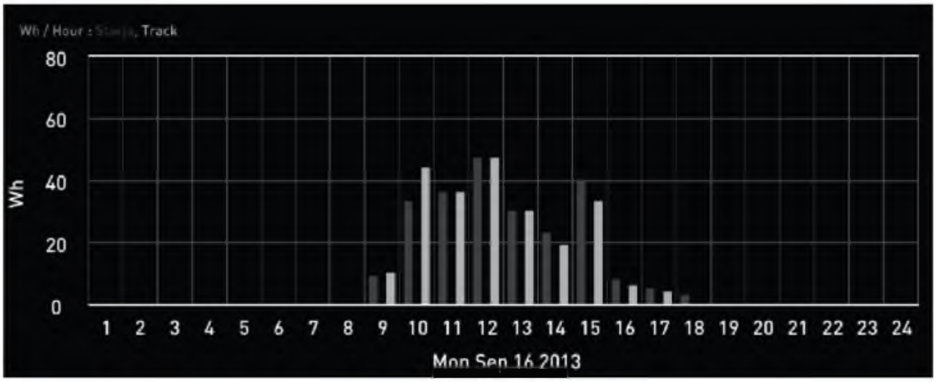


Fig. 15. Electrical energy generated by the tracking unit (Track) and fixed (Stacjo) per day, 16.09.2013, cloudy sky

## 7. Summary

On the basis of the measurements of radiation power density for a photovoltaic receiver as well as the comparative analyses performed as a function of its spatial positioning for different hours of the day, days of the year and locations, it was found that:

- the latitude angle has a considerable influence on the possibility of using solar energy which was determined on the basis of the results of measurements of radiation power density per second for two locations with different geographic location characteristics: Poznan (Poland) and Playa del Ingles (Spain), Fig. 2 and Fig. 3,
- the distribution of radiation power density depends considerably on the solar declination angle (the influence of the day of the year) and on the value of the hour angle (time of the day), which was demonstrated on Fig. 5, as well as Fig. 6 and Fig. 7,
- the value of short circuit current for photovoltaic modules depends on the illuminance value of the sunrays falling on the module. The measurements showed that six-fold decrease in the solar energy density value results in almost six-fold decrease in the current value. Thus, the value of the power generated by the system changes,
- the maximum momentary power for geographic locations similar to the latitude of Poland is observed between 12:00-13:00, and the minimum values are observed at sunrise and sunset,
- during morning and evening hours values of radiation power density obtained in the follow-up system are almost twice as high as in the fixed-point system. The result of the measurement recorded on 3 July 2013 at 08:14:44 a.m. in the follow-up system was 912 W/m$^2$, whereas in the stationary system the value was 502 W/m$^2$. Analogically, for evening hours on the same day at 6:11:03 p.m., the value was 601 W/m$^2$ in the oriented system and only 367 W/m$^2$ in the stationary system (Fig. 10). As the conducted measurements show, when the sky is clear during midday hours, the recorded solar radiation power densities become almost equal,
- it turns out that the impact of the degree of cloudiness on the difference in the amount of electric energy produced by both systems is important and influences the whole balance of the power system. When the sky is clear, the advantage of the follow-up system over the stationary one during morning and evening hours is significant. Between 8:00 and 9:00 a.m. the stationary system recorded 42 Wh of electric power, whereas in the two-axis follow-up system the value was 150 Wh of electric power. Between 6:00 p.m. and 7:00 p.m. production of electric power was 12 Wh, whereas the value in the oriented system was 100 Wh (Fig. 13),

- when cloudiness exceeds 80%, no significant differences in electric power are visible. Therefore, the advantage of the oriented system over the stationary one becomes less significant which was demonstrated on Fig. 15,
- the number of sunny hours per year for Playa del Ingles located at the latitude that is twice lower than the latitude of Poznan, is over 40% higher. As it is presented in tables 8, 9, 10 and 11 as well as on Fig. 11, the differences occur mainly during winter months,
- the lower the latitude, the higher the number of sunny hours, which can exceed 2500 h per year.

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