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ENERGY EFFICIENCY OF PHOTOVOLTAIC PANELS DEPENDING ON THE STEP RESOLUTION OF TRACKING SYSTEM

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Abstract. *The article presents an energy analysis of a 3.5 kWp photovoltaic installation placed on a two-axis tracking system, depending on resolution of step tracking system, that tracks apparent position of the Sun on the celestial sphere. Measurements were taken during July and August, months with similar solar radiation intensity. During the first month, the tracking system changed the spatial orientation of the photovoltaic panels with a frequency of 20 minutes, while in the second month the resolution of the tracking step was 120 minutes. The total energy production by the photovoltaic installation cooperating with the tracking system was 589.5 kWh and 579.85 kWh, for a tracking step resolution of 20 and 120 minutes, respectively. The monthly difference between the two analysed periods does not exceed 1.7%. However, when analysing the days with the highest energy production – exceeding 28 kWh/day, the photovoltaic installation which changed its spatial orientation with greater frequency produced 309.83 kWh, and with a smaller one 259.88 kWh. In the case of sunny, cloudless days, the difference in the efficiency of both solutions is equal to 19%. During days with lower solar radiation, the efficiency of the photovoltaic installations was similar. It can be concluded that increasing the step resolution of the tracking system increases energy production on sunny, cloudless days. It should be taken into account that increasing the frequency of changing the position of photovoltaic panels increased energy consumption by tracker motors from 2.48 kWh to 3.75 kWh, which constitutes 13.2% of the energy gain obtained over the entire tested period, but less than 1% during days with the highest amount of solar radiation.*

Keywords: photovoltaic panels, solar tracker, solar map, efficiency of energy production

EFEKTYWNOŚĆ ENERGETYCZNA PANELI FOTOWOLTAICZNYCH W ZALEŻNOŚCI OD ROZDZIELCZOŚCI KROKU ŚLEDZENIA UKŁADU NADĄŻNEGO

Streszczenie. *W artykule przedstawiono analizę energetyczną instalacji fotowoltaicznej o mocy 3,5 kWp umieszczonej na dwuosiowym układzie nadążnym, w zależności od rozdzielczości kroku śledzenia pozornej pozycji Słońca na sferze niebiskiej. Pomiary wykonano w trakcie lipca i sierpnia, miesięcy charakteryzujących się zbliżoną wartością natężenia promieniowania słonecznego. W trakcie pierwszego miesiąca, układ nadążny zmieniał orientację przestrzenną paneli fotowoltaicznych z częstotliwością równą 20 minut, natomiast w drugim miesiącu rozdzielczość kroku śledzenia wyniosła 120 minut. Całkowita produkcja energii elektrycznej przez instalację fotowoltaiczną współpracującą z układem nadążnym była równa 589,5 kWh oraz 579,85 kWh, odpowiednio dla rozdzielczości kroku śledzenia równego 20 oraz 120 minut. Miesięczna różnica między dwoma badanymi okresami nie przekroczyła 1.7%. Natomiast analizując dni o największej produkcji energii elektrycznej – powyżej 28 kWh, instalacja fotowoltaiczna zmieniająca swoją orientacje przestrzenną z większą rozdzielczością kroku śledzenia wyprodukoała 309,83 kWh, natomiast z mniejszą 259,88 kWh. W przypadku słonecznych, bezchmurnych dni, różnica w efektywności obu rozwiązań wynosi 19%. W trakcie dni charakteryzujących się mniejszą wartością nasłonecznienia, efektywność instalacji była do siebie zbliżona. Podsumowując, zwiększenie rozdzielczości kroku układu nadążnego powoduje wzrost produkcji energii elektrycznej w słoneczne, bezchmurne dni. Natomiast, zwiększenie częstotliwości zmiany położenia paneli fotowoltaicznych zwiększa zużycie energii elektrycznej z 2,48 kWh do 3,75 kWh, co stanowi 13,2% uzyskanego zysku energetycznego w całym badanym okresie, ale niespełna 1% w trakcie dni o największej wartości nasłonecznienia.*

Słowa kluczowe: panele fotowoltaiczne, system śledzący, mapa słoneczna, efektywność produkcji energii

Introduction

The first works on a system tracking apparent position of the Sun date back to the 1970s and 1980s. In 1979, Jerome H. Weslow and James A. Rodrian submitted a patent to the American Patent Office, which described a solution allowing to determine the apparent position of the Sun on the celestial sphere, the so-called tracker. The description concerned the method of moving and positioning the tracking system. Tracking systems are divided according to the number of rotation axes: single- and dual-axis solutions. The single-axis systems are divided into vertical (north-south) and horizontal (east-west) [17]. The advantage of single-axis solutions is the lower complexity of the tracking system, while the efficiency of the system with a movable vertical axis is higher compared to a movable horizontal axis. The issue of energy consumption of the tracking system has been described in many publications, the aim of which was to maximize energy production while limiting its consumption [12]. Solutions that significantly reduce energy consumption include tracking systems that use the change in the shape of the material due to temperature changes. In this solution, the electric motors were replaced with bimetallic steel and aluminum strips, which bend due to temperature changes, causing the photovoltaic panels to move [5].

1. Description of the problem

1.1. Types of algorithms

The apparent position of the Sun on the celestial sphere is determined by the tracking system controller using the differential, algebraic, hybrid and MPP (*Maximum Power Point*) methods [2, 14, 20]. The differential method uses data from photodetectors to determine the apparent position of the Sun on the celestial sphere. The photo-detector function can be performed by photoresistor, photodiode, phototransistor or small photovoltaic cell [6]. The photodetectors converts the solar radiation intensity into voltage, the value of which is measured by a microcontroller and, depending on its difference, the photovoltaic (PV) modules are rotated towards the photodetector with the highest value of solar radiation [8]. The effectiveness of the differential algorithm depends on the quality of the implemented algorithm and method the photodetectors are arranged [11, 18]. The algorithm determines the hysteresis value, which defines the step resolution of the tracking system. Too low resolution will reduce the efficiency of the photovoltaic installation, while too high resolution will increase the electricity consumption of the tracker motors. The voltage value of photodetectors can be used to determine atmospheric conditions and, in the case of heavy cloud cover, arrange the photovoltaic panels horizontally to the ground surface. There are two ways to set up photodetectors. The first involves the use of a partition that limits the amount of incident solar radiation. The second solution is to arrange the photodetectors at an appropriate angle, so that each detector determines one of the geographical directions. The advantages of this solution include low complexity of the measurement system, no calibration of the positioning of photovoltaic panels and response to changing lighting conditions. However, in the case of weak sunlight, no electricity is consumed by the tracker's engines. The disadvantages include susceptibility to interference caused by dirt or shading [1].

The algebraic method involves calculating or using a built-in map of the Sun's path [9, 19, 21]. The map contains information about the Sun's declination and azimuth for each day of the year at specific time intervals, therefore the tracking system controller does not require the use of external sensors. The lack of photodetectors means that the system does not respond to changing weather conditions [10]. The accuracy of determining the apparent position of the Sun depends on the size of the implemented solar map [7]. The more accurate the solar map causes frequent changes in the position of the PV panels. The simple design causes the system to have several drawbacks: lack of response to changing lighting conditions. The lack of use of detectors makes it impossible to eliminate the shading effect of photovoltaic surface.

The hybrid algorithm uses a combination of the two previously described methods. The positioning of photovoltaic panels is based on the data contained in the solar map. However, to precisely determine the apparent position of the Sun on the celestial sphere, data read from photodetectors is used, which eliminates the use of large solar maps. The applied of photodetectors enables the tracking system to respond to changing lighting conditions, thus eliminating all the above described disadvantages of the algebraic algorithm. The implementation of the solar map in the software of the tracking system controller does not increase its complexity, but it provides protection in the event of damage to the photodetectors. The accuracy of determining the apparent position of the Sun on the celestial sphere is comparable to the differential algorithm that searches for the maximum power point [3, 4].

The MPP algorithm involves searching for the maximum power point – tracking the maximum output power of PV panels [15, 16]. The change in the position of the Sun causes uneven illumination of the photovoltaic installation, which affects the output power of each module. The tracking system controller compares the voltage values and rotates towards the PV module producing the most energy. The presented solution requires the use of modules measuring the parameters of photovoltaic panels, which affects the complexity and costs of the measurement system. The advantage of the extensive measurement system is the ability to eliminate the phenomenon of shading photovoltaic modules. However, the step resolution of the tracking system can be determined based on the maximum difference in output power between individual panels. The advantage of this solution is the elimination of the shading effect of photovoltaic surface. The response to changing lighting conditions and the lack of electricity consumption by the motors in the event of poor sunlight. However, the disadvantages include the high complexity of the control system and susceptibility to interference, e.g. contamination of the photovoltaic surface.

1.2. Calculating the apparent position of the Sun

The azimuth angle and the elevation angle at solar noon are two angles that are used to orient photovoltaic modules relative to the apparent position of the Sun on the celestial sphere. These angles are calculated using "solar time". The regions of the Earth are divided into specific time zones. However, in these time zones, noon does not necessarily correspond to the time when the Sun is at its highest point in the sky. Similarly, sunrise is defined as the stage at which the Sun rises in one part of a time zone. However, due to the distance traveled in one time zone, the time at which the Sun actually leaves the horizon in one part of the time zone may be completely different than the "defined" sunrise (or officially recognized as the time of sunrise). Such assumptions are necessary, otherwise a house located one block from another would actually differ in time by several seconds. On the other hand, solar time is unique for each specific longitude. Consequently, to calculate the Sun's position, the local solar time is first found, and then the Sun's elevation angle and azimuth angle are calculated [10].

Solar declination is angle between the solar radiation falling towards the observer and plane of the Earth's equator. In the northern hemisphere, the declination is positive (from 0° to 90°), in the southern hemisphere it is negative (from 0° to -90°). The Earth's axial tilt is the angle between the Earth's axis and a line perpendicular to its orbit. The current value of the Earth's axial tilt is $\varepsilon = 23°26'$. The value of the declination angle can be written as follows

$$\delta = -23.44° \cdot cos\left[\frac{360°}{365.24} \cdot (N + 10)\right] \tag{1}$$

where N is the number of days since midnight UTC since the beginning of January. The value of +10 in the above equation is due to the fact, that the winter solstice occurs before beginning of year. The equation also assumes that the Sun's orbit is a perfect circle, and the ratio 360/365 determines the day number relative to the Earth's position in its orbit. However, the approximation used results in an error of 0.26°. Moreover, determining the value of the declination angle near the September equinox is subject to an error of +1.5°. Therefore, equation 1. may introduce an error up to 2°. The declination value can be calculated more precisely by not making an approximation and using the parameters of the Earth's orbit to estimate the value more precisely

$$\delta = arcsin[sin(-23.44°) \cdot$$

$$\cdot\, cos\left(\frac{360°(N+10)}{365.24} + \frac{360° \cdot 0.0167}{\pi} \cdot sin\left(\frac{360°(N-2)}{365.24}\right)\right)\Bigg] \tag{2}$$

where the number 2 in *N–2* is the approximate number of days after January 1th until Earth's perihelion. The calculation error does not exceed ±0.2°. Moreover, it may be less than ±0.03° if the value of "10" in the above equation is adjusted according to the date of occurrence of the December solstice in the previous year. These accuracies are comparable to advanced calculations using the Jean Meeus algorithm with an accuracy of 0.01°. The value of the Sun's declination can be determined using the following algorithm: PSA (*Position Sun Algorithm*); NREL – Sun Position Algorithm and Duffie & Beckman algorithm [13]. These algorithms are characterized by very high accuracy in determining the declination, which is desirable in solar radiation concentrator systems that use lenses for each photovoltaic cell.

The angle of elevation is the angular height of the Sun measured relative to a horizontal plane, which at sunrise and sunset is 0°, and when the Sun is directly above the object, it is equal to 90°. The angle of elevation can be calculated using the following relationship

$$\alpha_S = sin^{-1}[sin\,\delta\, sin\,\varphi + cos\,\delta\, cos\,\varphi\, cos(HRA)] \tag{3}$$

where φ – geographical latitude of the object, δ – declination angle depending on the day of the year. The hour angle (HRA) converts local solar time (LST) into a number of degrees that correspond to the Sun's path across the sky. Each hour corresponds to a change in the position of the Sun in the sky by 15°. The hour angle at noon is 0°, in the morning it is negative and in the afternoon it is positive. The HRA value is described by the following equation

$$HRA = 15° \cdot (LST - 12) \tag{4}$$

where LST – local solar time. Twelve noon local solar time is defined when the Sun is highest in the sky. The value of the azimuth angle is determined based on the following relationship

$$A = cos^{-1}\left[\frac{sin\,\delta\, cos\,\varphi - cos\,\delta\, sin\,\varphi\, cos(HRA)}{cos\,\alpha_s}\right] \tag{5}$$

Knowing all the parameters, the time of sunrise ($t_{sunrise}$) and sunset (t_{sunset}) can be calculated as follows

$$t_{sunrise} = 12 - \frac{1}{15} \cdot cos^{-1}\left(\frac{-\,sin\,\varphi\, sin\,\delta}{cos\,\varphi\, cos\,\delta}\right) - \frac{TC}{60} \tag{6}$$

$$t_{sunset} = 12 + \frac{1}{15} \cdot cos^{-1}\left(\frac{-\,sin\,\varphi\, sin\,\delta}{cos\,\varphi\, cos\,\delta}\right) - \frac{TC}{60} \tag{7}$$

For the geographical coordinates 50°46′N 20°37′E, the analysis of insolation depending on day of year was performed. The chart below (Fig. 1) shows the sunrise and sunset times and the length of the day expressed in hours.

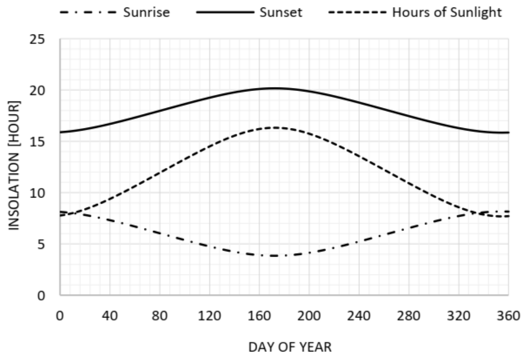

Fig. 1. The value of insolation depending on day of year for geographic coordinates 50°46'N 20°37'E

The time correction factor (TC) [minutes] takes into account changes in local solar time (LST) in a given time zone due to changes in longitude in the time zone

$$\mathrm{TC} = 4 \cdot (\mathrm{longitude} - \mathrm{LSTM}) + \mathrm{EoT} \qquad (8)$$

where EoT – equation of time, $LSTM$ – local standard time meridian. The $LSTM$ is a reference meridian used for a specific time zone and is similar to the prime meridian used for Greenwich time. The $LSTM$ is shown below

$$LSTM = 15° \cdot \Delta T_{GMT} \qquad (9)$$

where ΔT_{GMT} is the difference between local time (LT) and universal time (GMT), expressed in hours. The equation of time (EoT) is used to correct the average time to which the EoT value must be added or subtracted to obtain the real time. After calculating EoT based on the equation below, the result is expressed in minutes, with an accuracy of ½ minute

$$\mathrm{EoT} = 9.87 \cdot \sin(2\mathrm{N_d}) - 7.53 \cdot \cos(\mathrm{N_d}) - 1.5 \cdot \sin(2\mathrm{N_d}) \quad (10)$$

where N_d parameter is described by the relationship

$$N_d = \frac{360}{365} \cdot (N - 81) \qquad (11)$$

where N_d is expressed in degrees and N is the next day of year. The figure 2 shows the average time correction based on the time equation

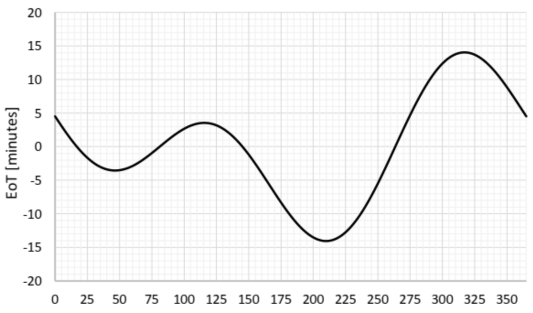

Fig. 2. The value of the equation of time (EoT) depending on day of year for geographical coordinates 50°46'N 20°37'E

Based on the chart it can be concluded that the real solar time and the average solar time are equal when the Sun is near the point of Cancer ($\delta = 23°27'$) or Capricorn ($\delta = -23°27'$) and near the place where $\delta = 10°$. At other times, the Sun passes through the meridian earlier or later so the equation of time takes a negative or positive value. The curve showing the difference between real and average solar time is called an analemma. The cause of the analemma is the movement of the Earth around the Sun and the inclination of the Earth's rotation axis to the orbital plane. The variable length of the day affects the height of the Sun, the highest point on the ecliptic analemma is reached during the summer and winter solstices. The difference between real and average solar time should be taken into account when developing solar maps for tracking system controllers that do not use external photodetectors.

2. Measurement setup

The measurement setup consists of 10 photovoltaic modules was placed on a system that tracks the apparent position of the Sun on the celestial sphere. The total power of the PV installation is equal to 3.5 kWp and the power of the inverter of 3.3 kW. The photovoltaic installation using a tracking system, the power of inverter should be slightly lower than the power of photovoltaic panels, in this case is 94%.

The tracking system was designed by the author of this article in a 3D modeling program. The maximum horizontal rotation angle is equal to 235°, whereas the vertical rotation angle 90°. The frame size is 542×440 cm and is adapted to 10 photovoltaic modules. The design and the finished device are shown in the figure 3.

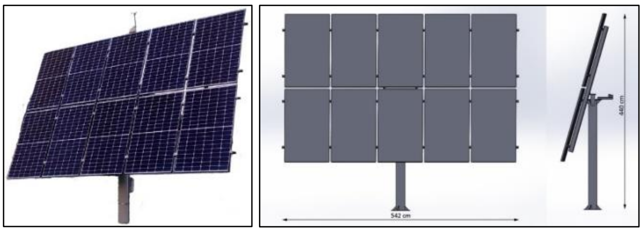

Fig. 3. Photovoltaic modules with tracking system (on the left), model 3D (on the right)

The tracking system has two electric motors with built-in limit switches, which maintain their position in the event of a power outage. To control the tracking system, was designed and created solar controller, that determines the apparent position of the Sun on the celestial sphere. The tracking system controller (Fig. 4) uses several modules, e.g. the GPS module (NEO-6M) to determine local geographic coordinates and the current date and time. The accelerometer and gyroscope module (MPU6050) and the magnetometer module (HMC5883L) determine the current position of photovoltaic panels relative to the Earth's surface. The ESP-12F Wi-Fi module is used to acquire measurement results. Four high-power motor driver module BTS7960 were used to control the electronic motors of the tracking with smooth PWM (*Pulse-Width Modulation*) regulation in the range of 0-100%. The motor voltage range is 6–27 V and the maximum current is 43 A. The BTS7960 module has a number of built-in protections, including: short-circuit, overload and thermal protection. The figure 4 shows the tracking system controller.

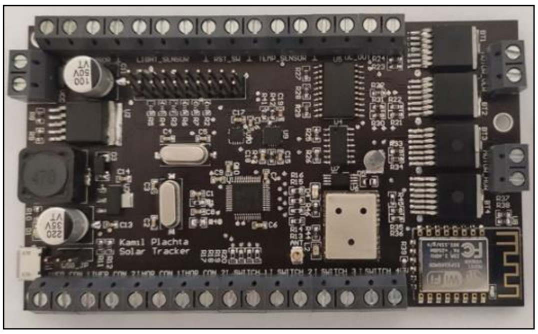

Fig. 4. Photo of the tracking system controller

After initialization, the controller measures the wind speed. If it is higher than the set protection value, the photovoltaic panels are placed in a safe position - parallel to the ground for 5 minutes. If the wind speed does not exceed the protection value, the controller collects data from the GPS module, accelerometer, gyroscope and magnetometer. Based on the received data, the Sun's path is calculated for a specific day of the year. The next stage is to precisely determine the spatial orientation of photovoltaic modules. The controller determines the current position of the PV modules in the horizontal plane based on the measurement of the change in the magnetic field value and the acceleration. However, the data obtained from the gyroscope and accelerometer are used to calculate the inclination angle relative to the Earth's surface.

In the horizontal system, the horizon plane and the direction of the vertical are determined for a given celestial sphere. The x and y axes lie in the horizon plane and determine the north and east directions, respectively, while the z axis points upwards. The location of a point on the celestial sphere is determined by the coordinates of azimuth A and height h. The height of an object on the celestial sphere is the angle between the plane of the horizon and the direction toward the object. The zenith distance is defined as the difference of 90° and the height h.

The translation of the xyz system around the z axis by the rotation angle α is shown in the figure 5.

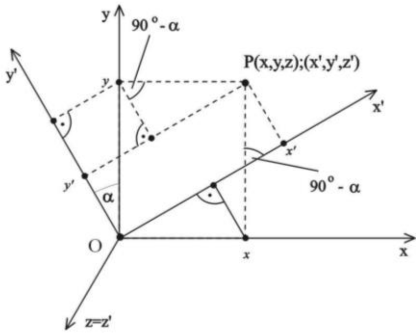

Fig. 5. Translation around the z axis for positive rotation by angle α

The coordinates of a point in the new coordinate system are described by the following equations:

$$\begin{gathered} x' = \mathrm{x}\cdot\cos\alpha + y\cdot\sin\alpha \\ y' = -x\cdot\sin\alpha + y\cdot\cos\alpha \\ z' = z \end{gathered} \tag{12}$$

To transform the horizontal system into the equatorial hour system, rotate the horizontal system around the y axis by an angle of 90°-φ, then by an angle of -180° around the z axis. In the case of translation in the opposite direction, rotate the hour system by an angle of 90°-φ around y axis and by an angle of 180° around the z axis. The transformation of the horizontal system into the equatorial hour system can be performed using the following system of equations:

$$\begin{gathered} \cos\delta\cos t = \sin h\cos\varphi - \cos h\sin\varphi\cos\alpha \\ \cos\delta\sin t = -\cos h\sin\alpha \\ \sin\delta = \sin h\sin\varphi + \cos h\cos\varphi\cos\alpha \end{gathered} \tag{13}$$

The inverse transformation can be performed using the equations:

$$\begin{gathered} \cos h\cos\alpha = \sin\delta\cos\varphi - \cos\delta\sin\varphi\cos t \\ \cos h\sin\alpha = -\cos\delta\sin t \\ \sin h = \sin\delta\sin\varphi + \cos\delta\cos\varphi\cos t \end{gathered} \tag{14}$$

Where the t can be calculated using the equation

$$t = arc\ tan\frac{\sin\alpha}{\tan h\ \cos\varphi + \sin\varphi\cos\alpha} \tag{15}$$

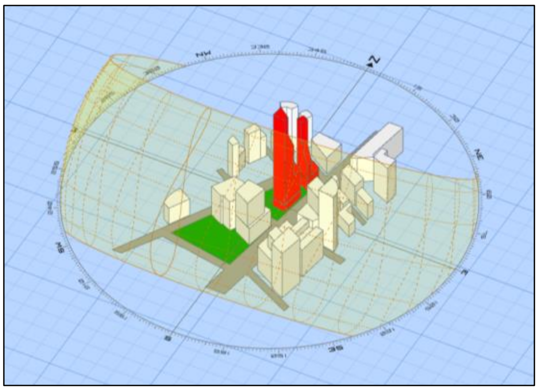

Fig. 6. Sun path for location 50°46'53"N 20°37'16"E (created with andrewmarsh.com)

The controller of tracking system calculates the apparent position of the Sun on the celestial sphere, creating a Sun path for each day of the year.

Visualization of the Sun's path for coordinate locations 50°46′53″N and 20°37′16″E, where the photovoltaic system is located.

3. Measurement results

The efficiency of a photovoltaic installation placed on a two-axis tracking system with a step resolution of 20 min and 120 min was measured. The two warmest months of the year were selected to verify the presented solutions: July and August. In July, the step resolution of the tracking system was 20 minutes, and in August it was 120 minutes. The monthly energy consumption of the electric motors was 3.75 kWh in July and 2.48 kWh in August. Electricity production depending on the day of the month is shown in figures 7 and 8.

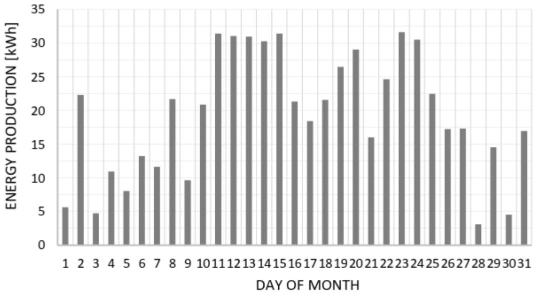

Fig. 7. Energy production with a step resolution of tracking system equal to 20 min

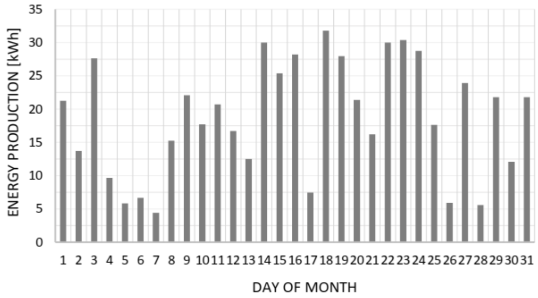

Fig. 8. Energy production with a step resolution of tracking system equal to 120 min

The total energy production by the photovoltaic installation cooperating with the tracking system was 589.5 kWh and 579.85 kWh, for the tracking step resolution of 20 and 120 minutes, respectively. The monthly difference between two presented solutions does not exceed 1.7%. The average daily energy production in July was 19.34 kWh and in August 18.71 kWh. Meteorological conditions were not the same for both tested months, but very similar. There were 16 days in each month when electricity production exceeded the average value. In order to better present the difference in efficiency of tracking system with a step resolution equal to 20 and 120 minutes, figure 9 shows the diffe-rences in the amount of energy produced for each day.

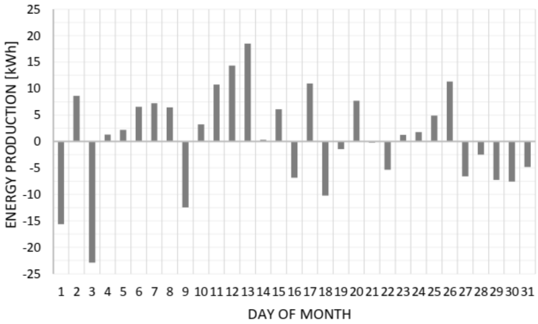

Fig. 9. The difference between the amount of energy produced by the system with a tracking step resolution of 20 min (above the x-axis) and 120 min (under the x-axis)

The data presented in the figure 9 shows that a higher tracking step resolution affects the number of days in which higher energy production was obtained. Discarding differences lower than 1 kWh, i.e. on the 14th and 21st day of the month, the system with a tracking step of 20 minutes ensured greater energy production during 17 days, while in the case of a tracking step of 120 min, the difference was visible during 11 days.

In order to reliably analyse the effectiveness of the presented solutions, it is necessary to compare the energy production results for days with similar solar radiation intensity. The chart below shows the distribution of electricity production in selected ranges.

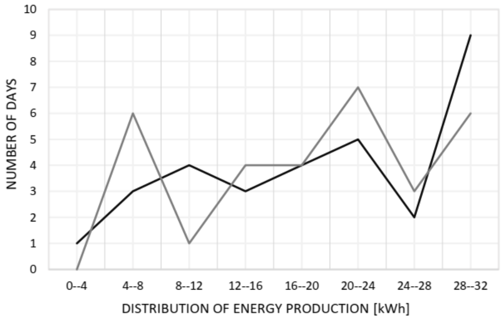

Fig. 10. Distribution of energy production for tracking step resolutions equal to 20 min (black line) and 120 minutes (grey line)

Based on the data presented in the Fig. 10, it can be concluded that the higher resolution of step tracking system enusred 9 days in which the amount of energy produced exceeded 28 kWh, for resolution of 120 minutes, only 6 days were obtained. In the case of a lower frequency of rotation of photovoltaic panels, the number of days with poor (4–8 kWh), medium (20–24 kWh) and good (28–32 kWh) energy production is similar. During the tested period, there were days with different meteorological conditions. Therefore in analysing effectiveness of presented solutions, the days with the highest intensity of solar radiation should be taken into account. During this days, the photovoltaic panels changing its spatial orien-tation with a higher tracking step resolution produced 309.83 kWh, while with a smaller one 259.88 kWh. The difference in the amount of energy produced is 19%. The increase of energy consumption by the tracker motors does not exceed 1% profit of energy produced. Based on the results obtained, it can be concluded that an appropriately selected step resolution of tracking system increases the amount of energy produced by photovoltaic panels.

4. Conclusions

The article presents an energy analysis of the photovoltaic installation placed on the two-axis tracking system with different resolution of step tracking. The measurements were taken during two months characterized by the greatest and similar solar radiation intensity.

The total energy production by the photovoltaic installation cooperating with the tracking system was equal to 589.5 kWh and 579.85 kWh for step tracking resolution equal to 20 and 120 min, respectively. The monthly difference between the two tested months does not exceed 1.7%. However, analyzing sunny, cloudless days in which the value of energy production exceeded 28 kWh/day, the photovoltaic panels changing spatial orientation with a higher step resolution produced 309.83 kWh, while with a smaller one it produced 259.88 kWh, the difference is 19%. During days with lower insolation (e.g. autumn and winter months) the effectiveness of the tested solutions was similar.

Based on the obtained results, it can be concluded that increasing the step resolution of the tracking system increases the amount of energy produced for months with the highest amount of solar radiation intensity. Increasing the frequency of changing the position of photovoltaic panels causes an increase of energy consumption from 2.48 kWh to 3.75 kWh, which constitutes 13.2% of the obtained profit of energy produced over the entire tested period. Considering days with the highest energy production, the increase of electricity consumption by the tracker motors was less than 1%. Therefore, the frequency of changing the position of photovoltaic panels relative to the apparent position of the Sun should be individually selected, depending on the sunlight conditions for each month of the year, so that the increase of energy consumption by the motors is not greater than the energy gained by photovoltaic panels.

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