Vol. 11, 2022, 75-83

sciendo

DOI: 10.17512/bozpe.2022.11.09

Construction of optimized energy potential

Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Energy efficiency analysis of 1 MW PV farm mounted on fixed and tracking systems

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Abstract: The article presents a comparison of results from a simulation of the energy production by a photovoltaic installation with a tracking system and a stationary PV farm in the PVSyst program. The analyzed 1 MW PV installations were located in the Kuyavian-Pomeranian Voivodeship in Poland. Energy production results obtained from the installation with a tracking system were compared with a stationary farm with panels placed at an angle of 20° and an azimuth 0°. The paper also presents the types of tracking systems and discusses the advantages of this solution and its risks compared to traditional panel mounting. The results obtained in the study indicated that the use of a tracking system increased the annual energy production compared to a stationary farm.

Keywords: photovoltaics farm, efficiency, solar tracking system

Please, quote this article as follows:

Walichnowska P., Mroziński A., Idzikowski A., Fröhlich S.R., Energy efficiency analysis of 1 MW PV farm mounted on fixed and tracking systems, Construction of Optimized Energy Potential (CoOEP), Vol. 11, 2022, 75-83, DOI: 10.17512/bozpe.2022.11.09

Introduction

Recently, due to the increase in fossil fuel prices and the need to reduce emissions of hazardous substances into the air, increasing numbers of countries are investing in renewable energy. Energy from wind, water and the sun is becoming

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a real alternative to traditional sources. Among the fastest growing industries of renewable energy sources is photovoltaics. According to the annual reports of the Institute for Renewable Energy the market of photovoltaic installations is constantly growing. According to available data, at the end of 2021 the installed capacity in the European Union in photovoltaics amounted to 158 GW (Idzikowski & Cierlicki, 2021; Korasiak, 2017; Mroziński, 2015).

The global solar tracker market is projected to grow from $6.88 billion in 2022 to $16.73 billion by 2029, at a CAGR of 13.5% in the forecast period of 2022-2029 (https://www.fortunebusinessinsights.com/industry-reports/solar-tracker-market-100448). IHS Markit has predicted 85% of ground-mounted solar panels added in the Americas during 2025 will be tracker mounted. That compares with just 22% of Asian projects and 43% in Europe (https://pv-magazine-usa.com/2022/02/22/solar-tracker-manufacturers-can-expect-a-boom-in-the-us-through-2025/).

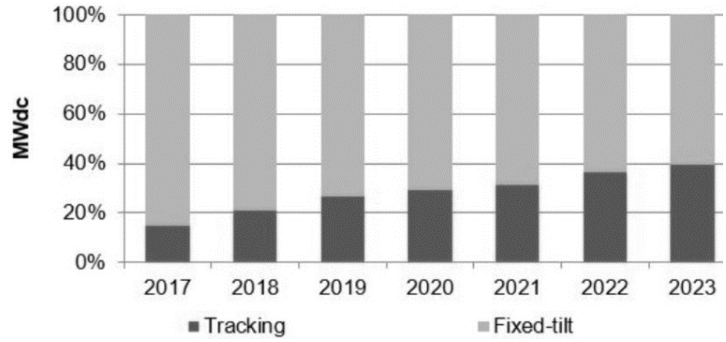

Fig. 1. Tracker share of global ground-mounted PV (IHS Markit report Global PV Tracker Market Report 2019)

Solar tracking systems are becoming more and more popular. The main task of the tracking system is to set the working surface of the solar farm at such an angle that it points directly towards the sun. For central Poland, the system with the use of trackers can produce 20-30% more energy per year. In order to use the solar energy reaching the photovoltaic modules practically, it is necessary to take into account their appropriate location in relation to the direction of the planet and their inclination to the horizontal to obtain the optimal angle of incidence of sunlight. Due to the number of planes in which the movement of photovoltaic panels takes place, the systems are divided into uniaxial and biaxial. Single-axis systems are installations with the possibility of moving the panels from east to west about one axis. Biaxial trackers enable the simultaneous movement of panels in relation to two axes of rotation. Two-axis tracking systems move from east to west with the possibility of changing the angle of inclination of the panels relative to the earth's surface. (Drabczyk & Panek, 2012; Fadil et al., 2013; Głuchy et al., 2014; Mirowski, 2015; Sumathi et al., 2017).

The article presents the results of a simulation of energy production by a photovoltaic installation with a tracking system and a stationary farm in PVSyst. The analyzed 1 MW PV installation was located in the Kuyavian-Pomeranian Voivodeship in Poland. The obtained results from the energy production of the installation with a tracking system were compared with a farm with a constant direction and angle.

1. Types of solar tracking systems

The tracking system is responsible for setting the working surface of the solar farm at such an angle that it points directly towards the sun. The installation can chose either a one-axis tracker or a two-axis tracker. The two-axis system is less common, as they require more complex mechanics, and therefore higher initial cost and more maintenance (Fig. 2). These systems are classified into:

1. One-axis trackers
   - horizontal north-south axis – the most popular system where it is possible to build long trackers that will track the sun from east to west during the day,
   - tilted axis – with a tilted axis analogous to horizontal N/S, the more complex design makes it impossible to build long trackers,
   - vertical axis – trackers have a fixed tilt and rotates around a vertical axis, following the sun.
2. Two-axis trackers
   - two axis – the tracker is permanently perpendicular to the sun's rays, receiving the maximum possible irradiance. In this case, the trackers are large, therefore necessitate robust mechanical supports. This type is less often used because of high maintenance costs,
   - frame with horizontal N/S axis – systems with rotating frames with horizontal North-South axis. In such a construction the frame follows the height of the sun, and a set of tables within the frame are permanently oriented in order to stay perpendicular to the sun's rays,
   - frame with horizontal E/W axis – similar to the frame with a horizontal N/S axis but the frame follows the height of the sun.

The following systems are also divided according to the control system used:

- open (passive) system, open loop control,
- closed system (active).

In closed systems, the control takes place in a closed loop but in an open system, the position of the tracker relative to the sun is controlled on the basis of mathematical models. The models are based on data that determines the position of the Sun on a specific date and time for a given latitude according to the astronomical calendar. Passive trackers are useful for simple PV systems, but are not the best for concentrated PV systems that require high targeting accuracy (Myczko et al., 2010; Sobuj et al., 2012; Zapałowicz & Rusicka, 2013).

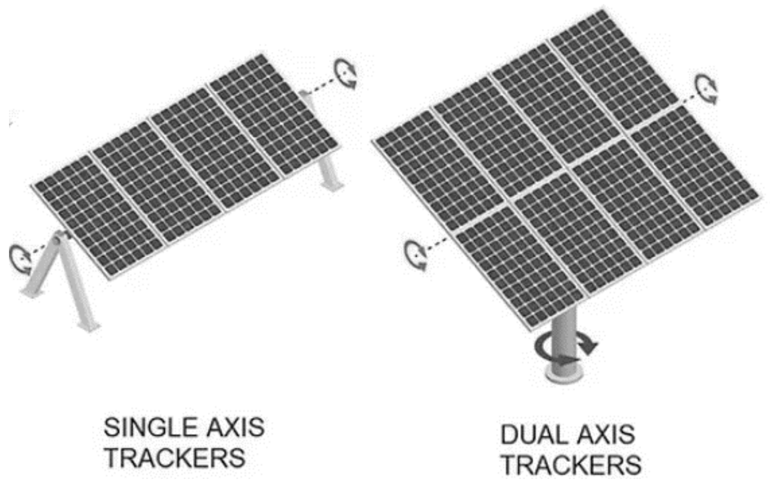

Fig. 2. Types of solar tracking systems
(https://www.renewsysworld.com/post/solar-trackers/)

Radiation concentrators are also used to increase the efficiency of tracking photovoltaic systems solar CPV (Concentrated Photovoltaics). CPV technology is a new evolving system of photovoltaic technology enabling the concentration of solar radiation on PV cells through the use of lenses or curved mirrors (Fathabadi, 2016; Rizk & Chaiko, 2008).

2. Analysis and results of the simulation

The simulation tests were carried out on two photovoltaic systems designed in the PVSyst program, operating in the same weather conditions, the first in a stationary system and the second, a solar tracking system. This made it possible to compare the effectiveness of the solar tracking system to the stationary system.

The first farm with a capacity of 1014 kWp was designed in a stationary system. The designed PV farm had 2028 modules arranged at a certain angle with a unit power of 500 Wp, dimensions 2220 mm x 1108 mm x 40 mm and a weight of 28.60 kg and 8 inverters SUN2000-105KTL-H1 (Fig. 3). The panels were arranged in 25 rows towards the south. The analysis was performed for the angle of 20° and for the distance of 4m between the rows of panels.

The second farm with a capacity of 1014 kWp was designed on the solar tracking system. For the simulation, one-axis trackers (horizontal north-south axis with rotating phi limits –60°/60°) were chosen. The designed PV farm had 2028 modules arranged at a certain angle with a unit power of 500 Wp, dimensions 2220 mm x 1108 mm x 40 mm and a weight of 28.60 kg and 8 inverters SUN2000-105KTL-H1 (Fig. 4).

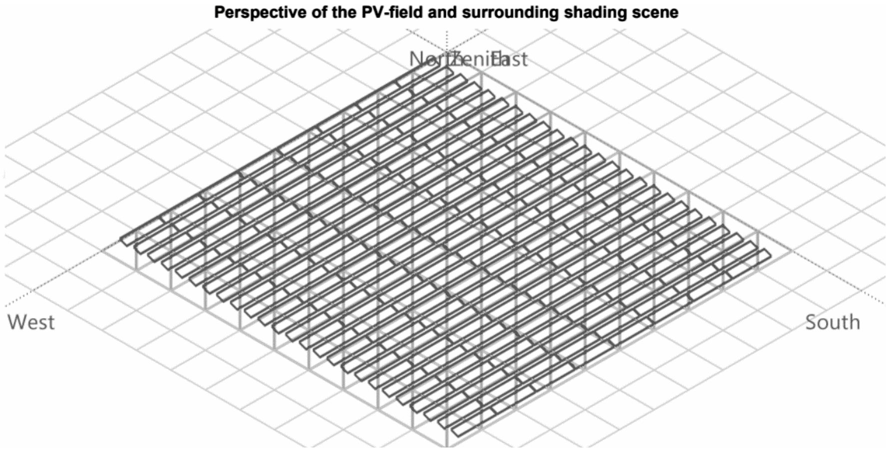

Fig. 3. A visualization of the stationary installation
(*own elaboration in PVSyst*)

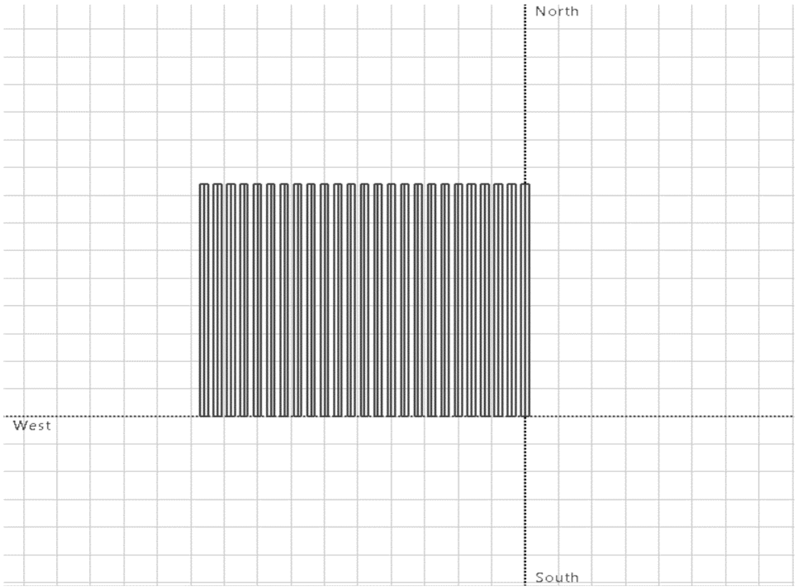

Fig. 4. A visualization of the solar tracking system
(*own elaboration in PVSyst*)

The analysis of the literature as part of the project shows that the area of the Kujawsko-Pomorskie Voivodeship in Poland is characterized by an amount of solar energy falling on the ground of 1237 kWh / m^2 per year. Figure 5 shows the average daily electricity yields during each month. The biggest daily differences can be observed in June. The lowest losses for the system occur in the solar tracking system in January. During the winter months, the program shows that the solar tracking system has a smaller amount of losses. While in the summer the stationary system has smaller losses.

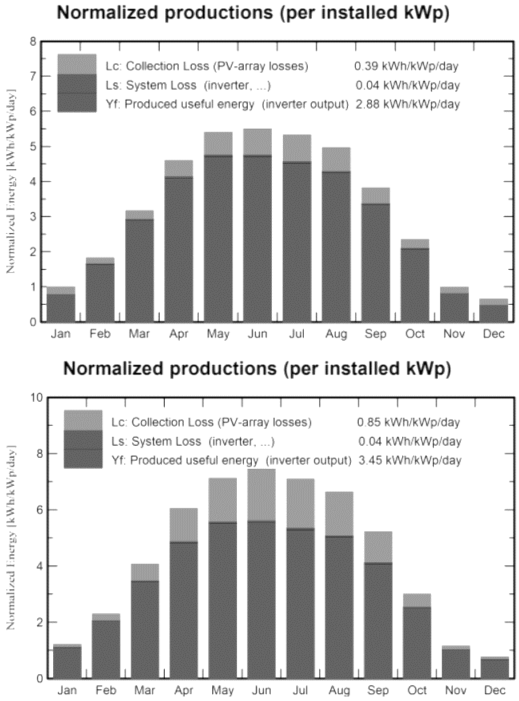

Fig. 5. The average daily electricity yields for each month obtained by the stationary farm and farm with solar tracking system (*own elaboration in PVSyst*)

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	ratio
January	18.5	10.41	-1.52	31.0	25.1	25.4	24.8	0.790
February	35.6	19.54	-0.42	51.2	47.3	47.8	47.1	0.908
March	78.8	41.77	3.31	98.2	94.0	92.8	91.7	0.921
April	122.1	60.43	8.98	138.1	132.7	126.8	125.2	0.894
May	158.4	78.70	14.33	167.6	161.1	150.4	148.6	0.874
June	161.2	76.82	17.24	165.1	158.4	145.6	143.8	0.859
July	159.2	82.98	19.85	165.2	158.3	144.4	142.6	0.852
August	139.8	69.13	19.17	154.1	148.1	135.7	134.1	0.858
September	94.3	43.77	13.87	114.7	109.9	103.4	102.2	0.879
October	54.2	30.51	8.91	72.9	68.5	66.8	65.9	0.891
November	21.4	15.70	4.62	29.7	25.6	25.4	24.9	0.826
December	13.2	9.49	0.73	20.4	15.9	15.8	15.3	0.740
Year	1056.8	539.26	9.15	1208.2	1144.8	1080.3	1066.2	0.870

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Fig. 6. Main results of the simulation for the traditional PV system (*own elaboration in PVSyst*)

Figures 6 and 7 show the percentage of energy production by perceived types of installations. In the analyzed period, the follow-up panel produced more energy per month than the traditional system. The highest production is reported for May – 169.6 MWh, which accounts for over 117% of the production of a stationary panel. In the tested installation, it is possible to estimate the greater daily loss in energy production for the solar tracking system. The loss of 0.85 kWh may be due to a misalignment of the vertical axis.

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	18.5	10.41	-1.52	37.8	35.5	35.9	35.3	0.922
February	35.6	19.54	-0.42	64.1	58.7	59.2	58.5	0.899
March	78.8	41.77	3.31	126.1	112.5	110.2	108.9	0.851
April	122.1	60.43	8.98	181.6	158.0	149.1	147.4	0.800
May	158.4	78.70	14.33	220.6	191.4	176.2	174.1	0.778
June	161.2	76.82	17.24	223.4	189.7	171.7	169.6	0.749
July	159.2	82.98	19.85	219.8	188.2	169.0	166.9	0.749
August	139.8	69.13	19.17	205.6	177.6	160.7	158.8	0.762
September	94.3	43.77	13.87	156.6	135.5	126.2	124.7	0.785
October	54.2	30.51	8.91	93.1	83.5	80.9	79.9	0.846
November	21.4	15.70	4.62	34.7	32.3	32.0	31.4	0.893
December	13.2	9.49	0.73	23.9	22.3	22.4	21.9	0.904
Year	1056.8	539.26	9.15	1587.3	1385.2	1293.4	1277.3	0.794

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Fig. 7. Main results of the simulation for the solar tracking system (*own elaboration in PVSyst*)

The tracking solar system produced approx. 20% more energy per year than the stationary system. From the presented results it can be concluded that the production capacity of the tracking solar installation is characterized by better electricity yield per year on average compared to the stationary system.

Conclusion

The purpose of the simulation was to compare the efficiency of the installations and the performance of different panel mounting systems. From the analysis of photovoltaic installations, it is shown that it is possible to increase the efficiency by a 20% conversion of light energy into electricity during the year by the use of the solar tracking system. Unfortunately, the biggest barrier to the widespread use of the solar tracking system is the higher cost of its installation compared to the traditional system and the cost of exploitation. It is estimated that the installation of panels on trackers increases the amount of the entire installation by 20%. In conclusion, designing a PV farm can improve its generated power and efficiency thanks to the existing solar tracking systems (Al-Roslan et al., 2018; Idzikowski et al., 2022; Szczerbowski, 2014).

Due to the high costs of this solution, we rarely find a solar tracking system in the household, but in the case of solar farms, this solution is used quite often. The use of tracking systems on PV farms maximizes the amount of energy obtained from a given area. However, it should be noted that the solar tracking system has advantages such as easier maintenance of photovoltaic panels. The movement of the panels reduces the likelihood of dust and other contaminants depositing on them. Another advantage is the convenient access to the panels. When it is necessary to carry out repair or maintenance, the photovoltaic system with a tracker can be easily placed in a convenient position. This is a great help, especially in the event of failure of panels inside the installation (Bugała & Frydrychowicz-Jastrzębska, 2012; Chong & Wong, 2009; Othman et al., 2013).

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