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Improving energy output and efficiency of PV installations using bifacial panels in public facilities

***Abstract**. The issue of improving the energy efficiency of photovoltaic installations is very important due to the limited location options in public facilities. Therefore, this paper presents the possibilities of improving the efficiency of photovoltaic installations in such facilities using bifacial PV panels. An assessment of the energy yields and installation efficiency depending on the roofing used is made, together with an economic analysis of the effects of bifacial panels.*

***Streszczenie.** Zagadnienie poprawy efektywności energetycznej w instalacjach fotowoltaicznych jest bardzo istotne ze względu na ograniczone możliwości lokalizacyjne w obiektach użyteczności publicznej. Dlatego też, w artykule przedstawiono możliwości poprawy wydajności instalacji fotowoltaicznych w tego typu obiektach przy zastosowaniu bifacjalnych paneli PV. Dokonano oceny uzysków energetycznych oraz wydajności instalacji w zależności od zastosowanego pokrycia dachowego wraz z analizą ekonomiczną skutków stosowania paneli bifacjalnych. **(Poprawa uzysków energetycznych oraz wydajności instalacji PV przy wykorzystaniu paneli bifacjalnych w obiektach użyteczności publicznej)**.*

Keywords: renewable energy sources, solar energy, PV panels, PV power plant.
Słowa kluczowe: odnawialne źródła energii, energia słoneczna, panele fotowoltaiczne, elektrownia fotowoltaiczna.

Introduction

Public buildings such as schools, kindergartens, etc. usually have similar geometry and are most often characterized by a flat roof. The issue of improving their energy efficiency can be achieved by using photovoltaic installations placed on the roof. Increasing the generation of photovoltaic power plants in limited roof space can be achieved by using bifacial modules. The effect of improving the efficiency of PV installations can be further increased by using roof coverings with a high reflectivity (albedo). This allows the investment payback period to be shortened, which is important for the investor.

Characteristics of bifacial photovoltaic panels

Bifacial photovoltaic modules, unlike monofacial ones, are characterized by double-sided absorption of solar radiation and conversion of it into electricity.

Bifacial technology assumes the use of solar radiation not only reaching directly, but also reflected and scattered to the greatest extent possible.

The largest share in energy production comes from radiation directly falling on the photovoltaic module. However, this is not the only type of radiation that affects the efficiency of a bifacial panel. Its double-sided nature uses not only the potential of sunlight scattered in the sky, but also the radiation reflected by the ground and the module's surroundings.

The internal structure of bifacial cells varies depending on the basic type of semiconductor [1-3]. The operation of a bifacial cell is shown in Fig. 1.

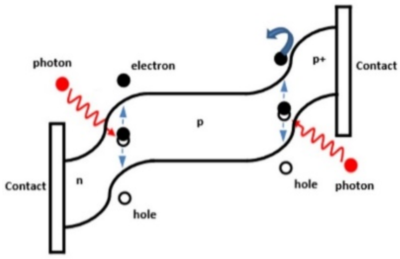

Fig.1. Energy band diagram of bifacial solar cell [1].

Changing the structure of the panels involves the introduction of additional parameters describing photovoltaic panels. In addition to the basic parameters characterizing traditional photovoltaic modules, these also include [4]:

– Bifacial Gain Energy

(1) $$BGE_{Isc} = \frac{I_{sc,back}}{I_{sc,front}}$$

where: $I_{sc,back}$ – short-circuit current of the rear side of the module under STC conditions, $I_{sc,front}$ – short-circuit current of the front side of the module under STC conditions.

Practically, this is the value that determines the photon absorption capacity of the rear side of the bifacial module.

G_{E} – irradiance value for measurements made using a lighting simulator [W/m2],

(2) $$G_E = G_0 + BGE_{Isc} * G_{rear}$$

where: G_0– irradiance of the radiation falling on the front side of the panel; G_{rear}– irradiance of the radiation falling on the rear side of the panel

FF_{bi} – filling factor of a double-sided cell

(3) $$FF_{bi} = \mathrm{pFF} - \frac{G_E}{G_0} * \left(\frac{U_{OC,front}}{U_{OC,bi}}\right) * (pFF - FF_{front})$$

where: pFF – fill factor that does not take into account losses in series resistance; $U_{OC,bi}$ - open circuit voltage of a double-sided cell.

Radiation falling on bifacial PV panels

The production of electricity from photovoltaic sources is characterized by high variability, which results from the dependence on many environmental factors [5] and aging of PV panels [6]. Weather changes are very difficult to predict accurately [7]. It is easier to estimate the amount of energy that can be obtained over longer periods (e.g. monthly). The operating efficiency of photovoltaic power plants depends to the greatest extent on the used type of PV panels, their location, the used inverter and other system elements [8, 9].

The amount of reflected radiation depends on the type of surface under the photovoltaic installation. The key parameter determining this phenomenon is the albedo coefficient (Table 1), which determines the ratio of the light reflected to the light incident on a given plane. The higher the value of the albedo coefficient, the more reflected rays reach the rear side of the bifacial module, which consequently leads to an increase in energy production by up to 30% compared to the monofacial module. A comparison of the power achieved by different types of photovoltaic installations is shown in Fig. 2.

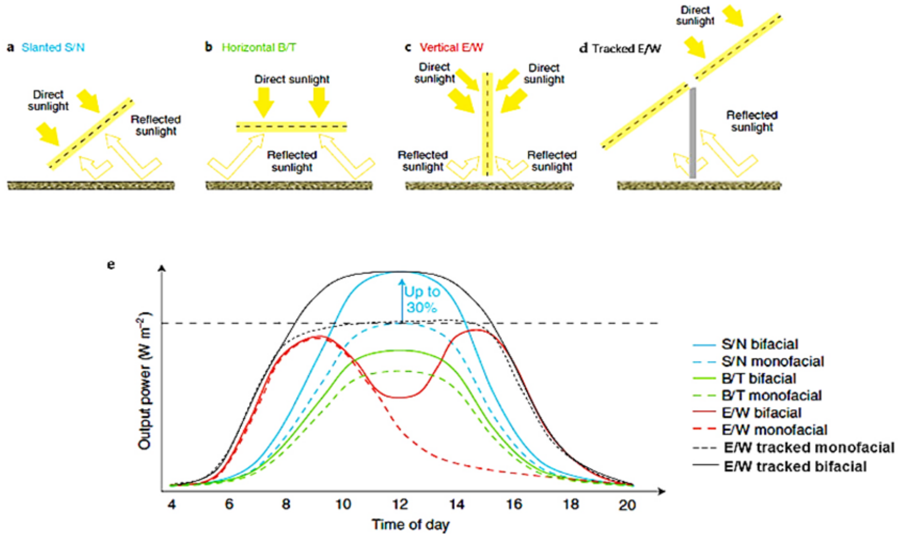

Fig.2. Methods of installing bifacial PV modules (a-d), where S/N - South/North, B/T - Bottom/Top, E/W - East/West; Comparison of power achieved by specific types of installations (e) [2].

Table 1. Albedo coefficient of selected surfaces

Surface type	Albedo
Concrete	0.16
Soil	0.08-0.14
Green grass	0.23
Gravel	0.27
Sand	0.2-0.4
Graphite bituminous waterproofing	0.1-0.2
Light gray roofing membrane or foil	0.62-0.75
White membrane or roof foil	> 0.8
Snow	0.45-0.95

Assumptions of the analysed PV installation

The analysed installation will be located on a building with a flat roof measuring 50x20 m and 10 m high. The roof area is 1,000 m^2. The geometry of the facility is typical for public utility facilities such as schools, kindergartens, etc. The building is located in north-eastern part of Poland in Bialystok, installation orientation to the south - azimuth 0°, module inclination angle is 15°, power of installation PV is 50 kW, inverter with power P=50 kW (type: Huawei - SUN2000-50KTL-M3). The installation will be mounted on a supporting construction with a ballast load adapted to the specific type of modules.

The variable elements in the analysis are the type of PV modules. The following will be compared in terms of energy yields:

– monofacial monocrystalline panel manufactured by Longi Solar, P= 500 Wp - catalogue no. LR5-66HIH-500M,
– bifacial monocrystalline panel manufactured by Longi Sola, P= 500 Wp, catalogue no. LR5-66HBD-500M Bifacial.

Table 2. Parameters of PV panels [10-12]

Parameters	Monofacial panel LR5-66HIH-500M	Bifacial panel LR5-66HBD-500M
Mechanical parameters		
Cell Number	132 (6x22)	132 (6x22)
Glass type	Tempered glass 3.2 mm	Dual glass. coated tempered glass 2.0 mm
Weight	25.3 kg	30.6 kg
Panel Dimension	2094 x 1134 x 35 mm	2073 x 1133 x 35 mm
Electrical parameters		
Maximum Power (Pmax)	500 W	500 W
Panel Efficiency	21.1 %	21.3 %
Operations parameters		
Operating Temperature Range	-40°C ~ +85°C	-40°C ~ +85°C
Power Tolerance	0 ~ +3%	0 ~ +5 W
Tolerance LZO i Isc	+/- 3%	+/- 3%
Nominal operating cell temperature	45 +/- 2°C	45 +/- 2°C
Bifaciality	-	70 +/- 5%
Temperature ratings (STC)		
Temperature Coefficient of Pmax.	-0.340%/ °C	-0.350%/ °C

Analysis of energy yields and efficiency of selected variants of PV installations in public facilities

The following variants will be analysed:

• Variant 1. Photovoltaic installation with monofacial modules on a standard structure and on a roof made of graphite bituminous waterproofing,

- Variant 2. Photovoltaic installation with bifacial modules on an elevated structure and on the roof made of graphite bituminous waterproofing (albedo = 0.2),
- Variant 3. Photovoltaic installation with bifacial modules on an elevated structure and on a roof made of green bituminous waterproofing (albedo = 0.45),
- Variant 4. Photovoltaic installation with bifacial modules on an elevated structure and on a roof made of grey bituminous waterproofing (albedo = 0.75),
- Variant 5. Photovoltaic installation with bifacial modules on an elevated structure and on a roof made of white membrane or roof foil (albedo = 0.95),

In all analysed variants, the power of photovoltaic installation was P= 50 kW. The installation includes 100 modules with a power of 500 W each. The system was divided into 5 strigs of 20 photovoltaic modules, taking into account the electrical input parameters of the inverter. The considerations assume that the installation power is limited to the value for which only notification to the DSO is required, without the need to change the connection capacity for typical public utility facilities. educational.

A 3D-model was created for all design situations, after by analysing the dimensions of the building and the number of modules and strings. The photovoltaic system was divided into 10 rows of 10 panels each. The rows were spaced 4 meters gap to minimize the shading of the panels. The prepared model allowed for the analysis of energy yields and system efficiency in all indicated design variants.

Meteorological data at the workplace of the analysed PV installation are presented in Table 3.

Table 3. Meteorological data

	Average radiation value per horizontal surface	Average temperature	Average wind speed	Relative humidity
Month	kWh/m²	°C	m/s	%
January	18.6	-3.70	2.9	88.3
February	34.0	-2.59	2.8	85.5
March	80.3	1.70	2.8	75.5
April	116.6	7.94	2.6	66.9
May	161.4	13.58	2.4	69.2
June	166.2	16.53	2.3	70.3
July	167.4	19.29	2.1	71.8
August	140.4	18.13	2.0	73.2
September	91.4	12.47	2.1	81.5
October	51.2	7.40	2.4	83.7
November	19.4	3.17	2.8	89.2
December	13.4	-0.99	2.8	88.4
Annually	1060.2	7.8	2.5	78.6

The results of the simulations of individual variants allowed for a detailed comparative analysis of energy yields and the efficiency of photovoltaic installations using monofacial and bifacial modules. The irradiation values on both sides of the PV modules depending on the surface albedo value are presented in Fig. 3

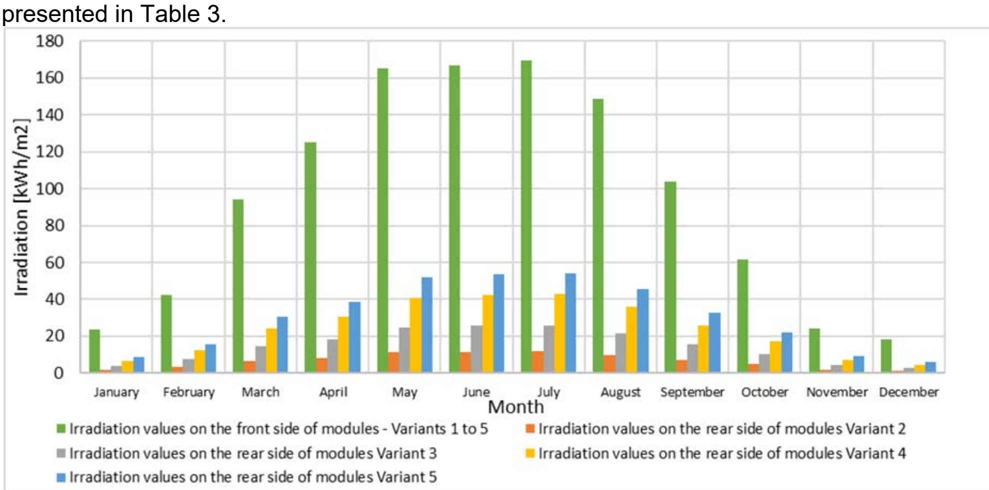

Fig.3. Irradiation of both sides of the PV module depending on the surface albedo coefficient value.

Green columns show the irradiation values on the surface of monofacial modules and on the front side of bifacial modules. The columns in the remaining colors show the irradiation value on the rear surface of bifacial modules in each variants. The most advantageous of the analysed variants allows for the introduced into grid additional energy in the amount of 9,824 kWh, i.e. 19% more in relation to the use of single-sided modules. The annual energy introduced into the grid of all analysed variants and percentage values in relation to the use of single-sided modules are presented in Fig. 5 and Fig. 6.

The key value of the analysis is the PR factor (Performance Ratio) of the efficiency of the tested photovoltaic installations. It is a general indicator for comparing systems: the higher its value- the more efficient the installation.

$$PR = \frac{E_{out}}{E_{STC}} \tag{4}$$

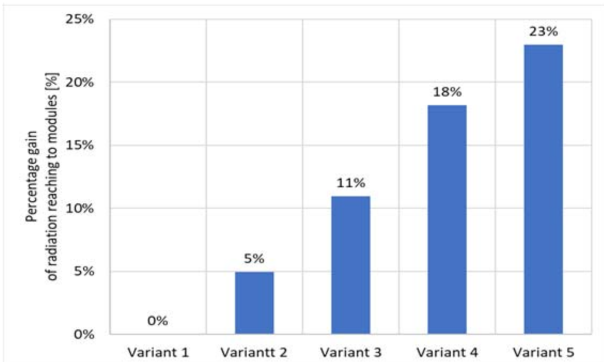

Fig.4. Percentage gain of radiation reaching to modules.

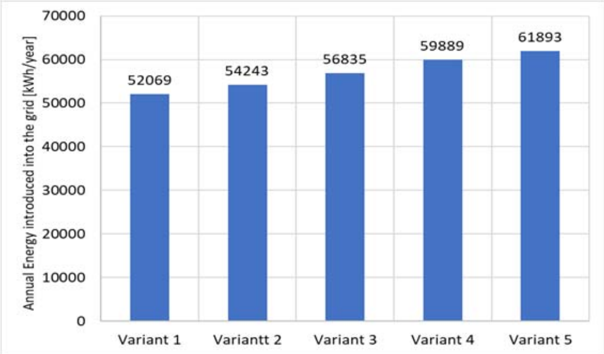

Fig.5. Annual energy introduced into the grid in each variants.

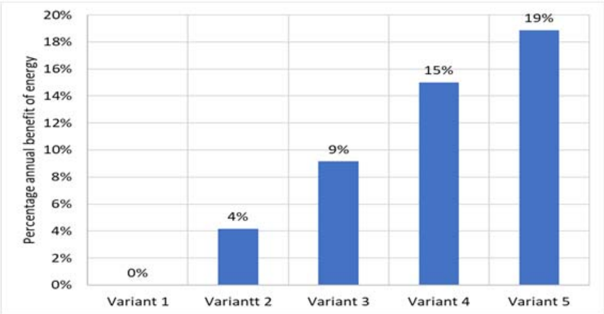

Fig.6. Percentage annual gain of energy introduced into the grid.

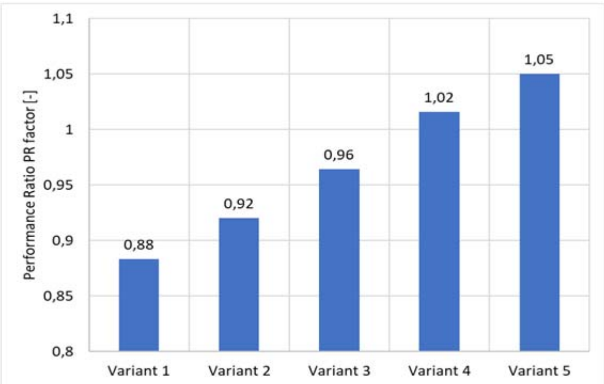

Fig.7. Performance Ratio PR factor of the efficiency of the tested photovoltaic installations.

Table 4. **Costs of constructing photovoltaic installations in the analysed variants**

Elements of installations PV	Cost of monofacial installation PV [PLN]	Cost of bifacial installation [PLN]
PV panels	70 000	77 000
Supporting construction	25 000	27 500
Inverter	15 000	15 000
Conductors and electrical equipment	2 500	2 500
Assembly	10 000	10 000
Sumary	**122500**	**132000**

Important information is also the annual distribution of electricity forecast to be introduced into the power grid. Graphs of the energy forecast to be introduced into the power grid in the following months for all analysed variants are presented in Fig. 8.

The analysis shows that in the winter period (November - February) the amount of energy produced in the installations is very similar. This is the result of a small number of sunny days and a short period of exposure to the Sun. It is also necessary to take into account the possibility of snow cover, which eliminates the possibility of producing energy from the front of the PV modules, and at the same time increases the albedo value of the ground, which increases the amount of energy generated from the rear surface of the PV module. The advantage of using bifacial modules with the simultaneous use of roof coverings with a high albedo coefficient is most visible in the period from early spring to autumn. However, the basic criterion for selecting the type of installation should be economic analysis. Due to frequent changes in the methods of settling electricity from PV installations and unstable electricity prices, the payback period method was used for analysis.

The costs of implementing the PV installation in the analysed variants are presented in Table 4, but the costs do not include the costs of roofing, as it is assumed that roofing is included in the costs of the building. The total cost of installation using bifacial modules and a dedicated supporting structure is 7.75% higher than the base version with single-sided modules.

A graph showing the payback period for the installation in all design variants is shown in Figure 9, with the energy price per 1 kWh being PLN 1.3 for the purposes of the analysis.

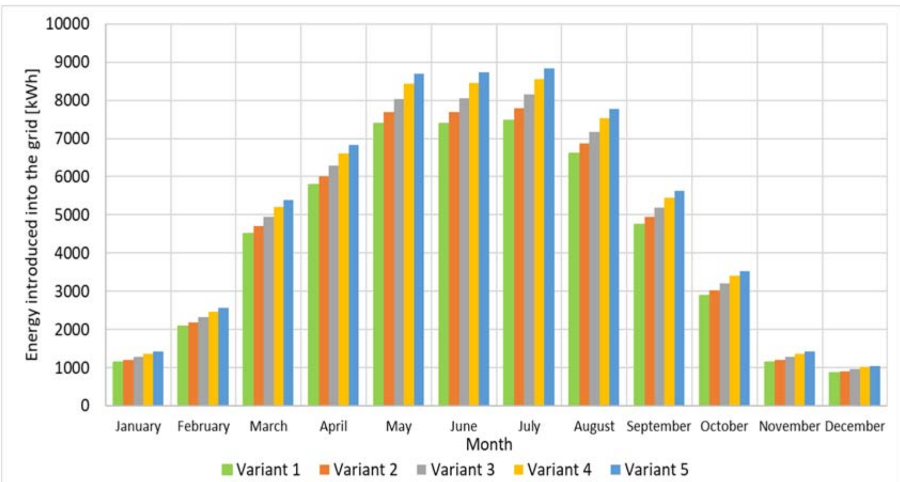

Fig.8. Forecasted energy introduced into the grid in the analysed variants of PV installations.

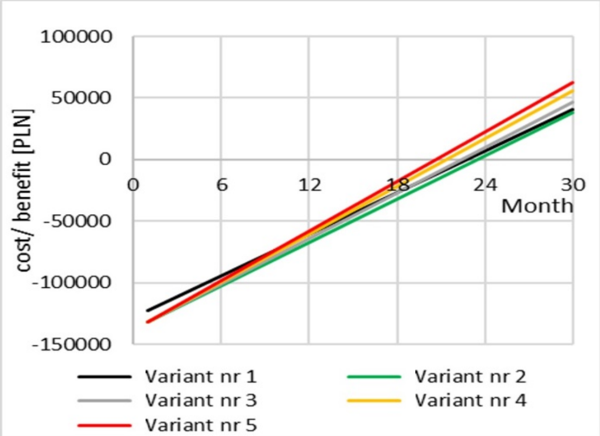

Fig.9. The payback period for the building of individual PV installation variants.

Summary

A PV installation using bifacial panels requires a supporting structure that allows the panels to be raised to a higher height. Taking into account the higher price of bifacial panels, the cost of the entire 50 kW installation is 7.5% higher than the base variant. The payback period for monofacial and bifacial installations on graphite and green felt differs by only 1 month and is approximately 22.5 - 23.5 months. In the case of a roof slope with an albedo coefficient above 0.75, the payback time for a bifacial installation is 20.5 months. These values indicate that when it is possible to use roofing with a high albedo coefficient during the construction or renovation of a public utility facility, the installation of bifacial modules on a raised structure is most justified.

The benefits in terms of increasing energy generation reach approximately 20% and are highly dependent on the ground albedo. Installations with bifacial modules allow for the greatest additional yields when located on buildings with a flat roof, which corresponds to the typical geometry of public buildings. The use of bifacial modules also increases the possibilities in terms of how to arrange the modules. For example, positioning bifacial modules vertically in the east-west direction allows for the extension of the daily generation time, which allows for better adjustment to the recipient's demand curve. Thanks to this, it is possible to achieve a higher level of self-consumption and reduce the size of the potentially needed energy storage.

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