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Consequences of suboptimal design of Building Integrated Photovoltaic Installation – a case study for Gdansk, Poland

***Abstract**. The carried out analysis concerns 2 kWp building integrated photovoltaic installation (BIPV) at the Chemistry Faculty of Gdansk University of Technology. It was proven that the generated energy data for every month diverge significantly from the expected vales. It is corelated with suboptimal orientation of the installation itself, as well as with the tilt angle varying from optimal.*

***Streszczenie.** Przeprowadzona analiza dotyczyła uzysków energetycznych 2 kWp instalacji fotowoltaicznej zintegrowanej z budynkiem (BIPV) Wydziału Chemicznego Politechniki Gdańskiej. Wykazano, iż dla każdego miesiąca otrzymane wartości generowanej energii wyraźnie odbiegają od spodziewanych. Jest to skorelowane z nieoptymalną orientacją samej instalacji, jak również kątem nachylenia obiegającym od optymalnego. (**Analiza uzysków energetycznych 2 kWp instalacji fotowoltaicznej zintegrowanej z budynkiem**)*

Keywords: photovoltaic installation, BIPV, solar energy, efficiency
Słowa kluczowe: instalacja fotowoltaiczna, BIPV, energia słoneczna, sprawność

Introduction

The 2021 World Energy Outlook has foreseen the rapid rise of energy demand, which was previously stalled due to the breakout of the pandemic. As such, global energy need is placed at 4.6% raise and CO_2 emissions are expected to grow by 4.8% in comparison to year 2020 [1]. However, it is also worth noting that the demand for renewable energy increased by 3% in 2020 and in 2021 is believed to by another 8%, with solar and wind farms being the primary source of this growth [1]. Such trend may lead to the assumption that photovoltaics (PV) would play an important role in the upcoming years, as an alternative energy source aiding to mitigate CO_2 emissions. Especially, once it is considered how diversified PV systems can be. Not only is there a separation between on-grid and off-grid solar plants [2], but also a distinction for ground-mounted, roof-mounted or building-integrated installation [3 – 5]. The latter is a particularly promising energy source for urban applications, since it does not reduce the available ground area, and can be implemented as a façade on external walls, or as shutters, blinds, and even windows [6].

In this work, the authors provide the analysis of energy generated by a BIPV located in Gdansk, Poland. The timeframe was chosen for three consecutive years, starting from January 2019. This research aims to investigate the advantages and disadvantaged of such solar system.

Methodology

The photovoltaic installation considered in this analysis is a face mounted BIPV on the south-east site of Chemistry C building of Gdansk University of Technology, as shown in the Figure 1. Its geographical coordinates are 54.37°N and 18.62°E, and tilt angle is 90°.

Fig.1. View of the Chemistry C building with BIPV installation

Total surface area of above mentioned installation is 12.89 m^2, which contributes to 8 glass-glass Bruk-Bet Solar BEM-250 modules manufactured in monocrystalline silicon technology. An entire technical specification measured in Standard Test Conditions (1000 W/m^2, 25°C, AM 1.5) for a single BEM-250 module is listed below in Table 1.

Table 1. BEM-250 module parameters taken at STC

Electrical/Physical parameter	Value
Maximum power [Wp]	250
Maximum power current [A]	8.80
Maximum power voltage [V]	28.45
Short circuit current [A]	9.20
Open circuit voltage [V]	38.80
Efficiency [%]	15.51
Maximum system voltage [VDC]	1000
Tolerance [Wp]	0 +4.99
Power temperature coefficient [%/°C]	-0.39
Temperature coefficient current [%/°C]	0.03
Temperature coefficient voltage [%/°C]	-0.31
NOCT [°C]	43±2
Cells	Monocrystalline
Number of cells	54
Length [mm]	1634
Width [mm]	986
Thickness [mm]	8
Weight [kg]	27
Junction box	IP67
Bypass diodes	1
Reverse current protection [A]	15

Based on the data provided by the manufacturer a relationship between irradiance and relative drop in both short circuit current and open circuit voltage was drawn and is presented in Figure 2. The formula (1) used for this calculation was as follows:

$$d = \frac{x_0 - x}{x_0} \times 100\% \tag{1}$$

where: d – relative drop in analyzed physical quantity, x_0 – value of physical quantity at 1000 W/m^2 solar irradiance, x – value of physical quantity at a different solar irradiance.

Current and voltage values exhibit a discrepancy in relationship for the steady decrease in irradiance. Short circuit is much more sensitive for varying levels of solar energy, which can be explained by lower amount of electrons freed from chemical bonds at smaller irradiance levels [7, 8]. On the other hand, values for open circuit voltage drop insignificantly even when irradiance is greatly reduced. Such effect is the reason why the energy produced by the photovoltaic installation heavily depends on the amount of solar radiation reaching solar cells.

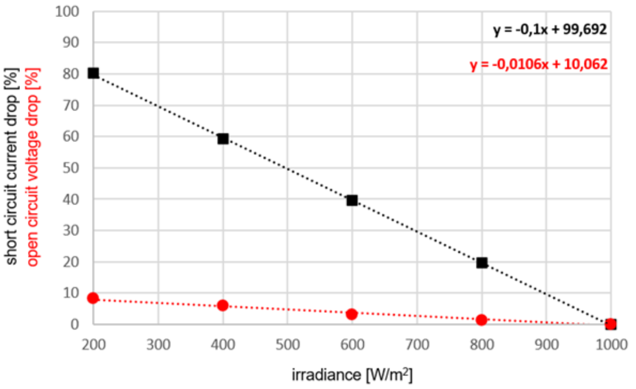

Fig.2. Relative change of short circuit current and open circuit voltage for different irradiance values

Based on the graph above a relationship (2) for short-circuit current in a function of irradiance was proposed:

$$I_{SC} = I_{SC0} \times (1 - 0.1 \times \frac{\Delta E}{100}) \tag{2}$$

where: I_{SC} – present short-circuit current value [A], I_{SC0} – short-circuit current vale at 1000 W/m^2 [A], ΔE – difference between 1000 W/m^2 and present irradiance value [W/m^2].

Efficiency for the whole PV installation was calculated following the formula (3) below:

$$\eta = \frac{G}{H \times S} \times 100\% \tag{3}$$

where: η – monthly efficiency [%], G – total energy generated in each month [kWh], H – monthly sum of solar irradiation [kWh/m^2], S – surface area of the whole installation [m^2].

Values of total energy and monthly sum of solar irradiation are obtained from monthly reports that are available for Fronius software, monitoring PV installation.

PV-GIS

Internet program PV-GIS was chosen for carrying out the comparative analysis between the actual BIPV and simulated values for the optimal installation placement. It is available online and helps to calculate expected energy and irradiation data for any PV installation, provided its geographical coordinates and boundary conditions are entered [9]. For the purpose of the examination SARAH2 solar radiation database and crystalline silicon technology were selected. Moreover, it was stated that PV installation is building integrated with optimal slope 36° and azimuth 0° [7], generates 2 kWp and experiences 14% system loss. Location was provided by assigning geographical coordinates to 54.37°N and 18.62°E.

Results and discussion

Solar radiation measured during three consecutive years for the existing BIPV and obtained from PV-GIS simulation are shown in Figure 3.

There is an obvious discrepancy in irradiation between data suggested by PV-GIS and that obtained in real-time by PV installation. During three year's timespan solar radiation for BIPV almost never reaches predicted values, with some month showing a mismatch of over 50% for a few months. It could be easily assumed that such disparity is closely linked to suboptimal placement of the installation itself, as it should be facing directly south for the Northern hemisphere [10]. Additionally, an even bigger impact is associated with tilt angle varying from suggested range 39° – 43° for Poland [11]. This further limits the amount of solar radiance facing PV installation, leading to reduction of energy yield, which is clearly present in the Figure 4. It shows the annual energy values generated by the installation, as well as energy data suggested by PV-GIS.

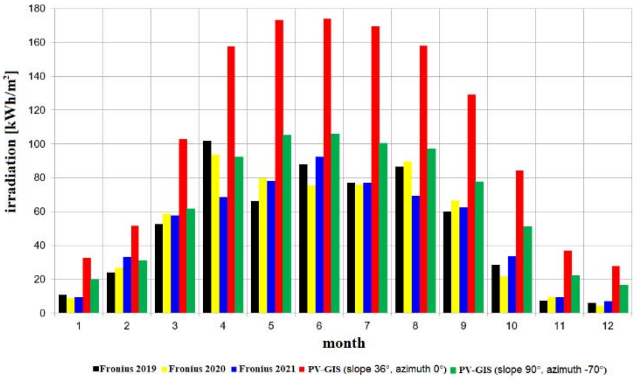

Fig.3. Monthly irradiation from BIPV (mostly East direction, 90° tilt angle), PV-GIS at optimal conditions (South direction, 36° tilt angle) and PV-GIS at the actual conditions (East-South direction, 90° tilt angle)

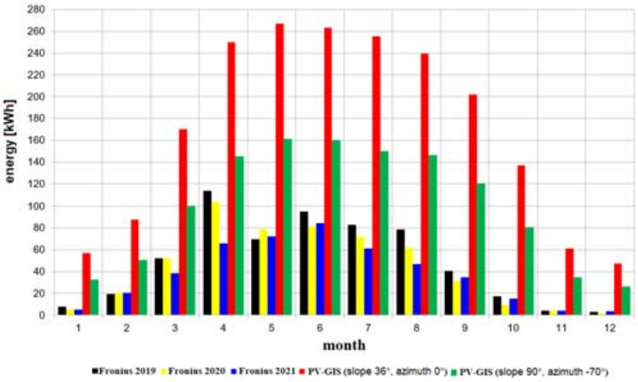

Fig.4. Monthly energy generation from BIPV (mostly East direction, 90° tilt angle), PV-GIS at optimal conditions (South direction, 36° tilt angle) and PV-GIS at the actual conditions (East-South direction, 90° tilt angle)

It is noticeable that throughout three full years, energy generation is significantly lower for each month when comparing it to predicted PV-GIS values. This aspect has been analyzed deeper, as total annual data were calculated for BIPV and PV-GIS simulation and gathered in Table 2.

Table 2. Total annual irradiation (H) and energy values (G) gathered for Fronius, PV-GIS at optimal conditions (OPT) and PV-GIS at the actual conditions (ACT)

	H [kWh/m^2]			G [kWh]		
	Fronius	*OPT*	*ACT*	*Fronius*	*OPT*	*ACT*
2019	609	1300	780	584	2038	1206
2020	611	1300	780	521	2038	1206
2021	598	1300	780	454	2038	1206

This leads to believe that the major mismatch between observed and predicted energy values stems from two key components – tilt angle and orientation with respect to the local geographic coordinates. Since those two elements are far from optimal it is reflected in generated energy yield.

Other minor factors may also play some role, for instance – occasional partial shadowing of BIPV by the trees in the park nearby or heavy machinery operating on the access road directly in front of the installation. One more factor that may be taken into consideration after longer exposition to external conditions is dust build-up and the front surface of solar modules, which also impact negatively the energy generation [12].

Conclusions

BIPV mounted on the façade of Chemistry building at Gdansk University of Technology is a solution mitigating some of the object's need for electricity. Another of its unquestionable advantages is contribution to reduction in CO_2 emissions.

On the other hand, carried out analysis helped to trace two important issues diminishing annual energy yield, such as suboptimal tilt angle, azimuth. It should be therefore stated that designing any BIPV system needs to prioritize those elements and if possible opt for a placement with the most orientation for the given region. Additional aspects, for example shadowing from surrounding architecture or moving objects is an issue that may be impossible to eliminate completely. And lastly, soiling accumulation over time also decreases PV installation's ability to operate efficiently. There are some measurements that can be taken to prevent it, namely – systematic manual cleaning in the time period with heavier pollution [13], electrostatic or mechanical cleaning [14], or incorporating surface enhancement on the front glass cover of each solar module [15].

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