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ALTERNATIVE ENERGY SOURCES PROJECT
Chemical Apparatus and Theory of Machines
Faculty of Chemistry Gdańsk University of Technology

INTRODUCTION TO DESIGNING A PHOTOVOLTAIC INSTALLATION INCLUDING INFLUENCE OF EXTERNAL FACTORS AS WELL AS PROJECT DECISIONS ON THE ENERGY YIELD

2. Purpose and range of the project

The project aims to familiarize students with the following topics:

- Designing the photovoltaic installation for different connections between modules.
- Determining electrical parameters for the photovoltaic installation in laboratory and external conditions.
- Analysis of the energy generated by the photovoltaic installation with comparison to data obtained by PV-GIS.

3. Introduction to the project

2.1. Photovoltaic effect

The principle of solar cell operation is based on photovoltaic (PV) effect, namely direct conversion of solar radiation energy to electric energy. Semiconductor material absorbs photon energy, which results in releasing electrons from interatomic chemical bonds. However, not all of the semiconductors can be used in photovoltaic cell production. It is primarily dependent on energy gap, E_g . Lower values of E_g permit wider solar spectrum to be absorbed, but at the same time it is linked to lower photovoltaic voltage generation [1][2]. Appropriate adjustment of solar battery's spectral sensitivity to spectral radiation characteristics is an extremely important aspect. Nowadays, around 90% of Polish market consists of silicon based mono- and polycrystalline first generation modules, while the rest belongs to second generation amorphous silicon ($a-Si$), copper indium selenide (CIS) and copper indium gallium selenide (CIGS) [3]. The scheme of the photovoltaic cell structure is presented in Figure 1.

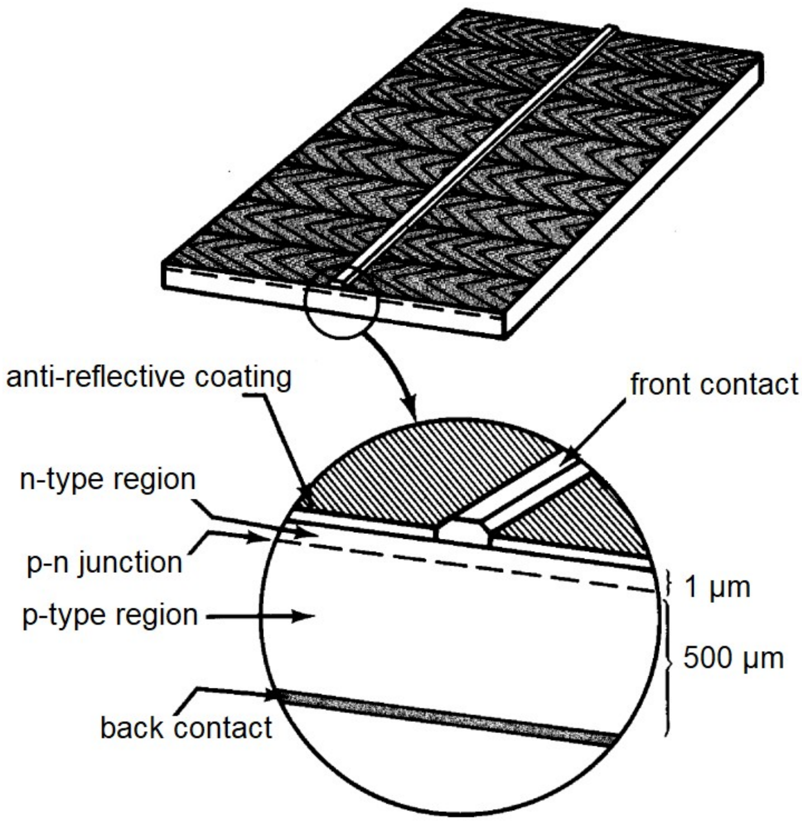


Fig. 1. Silicon based photovoltaic cell layout [4]

The primary element of solar cell is p-n junction, as shown in Figure 2. In the silicon based solar battery electron and hole conductivity are obtained by doping the material with phosphorus and boron respectively. At room temperature it may be assumed that all acceptor dopants n_A in type p semiconductor and donor dopants n_D in type n semiconductor are ionised. Then, there are grounds for applying such an approximation that equates concentration of majority carriers to their dopants. Once p-n junction is formed, there is a high carrier concentration gradient on the border area, which allows for electron and hole diffusion and depletion layer formation. Therefore, space charge of thickness d is created – positive on the n site, because electrons diffuse into p region, and negative on the p site, following the same relation. The resulting potential difference between area p and n is called diffusion voltage, U_d .

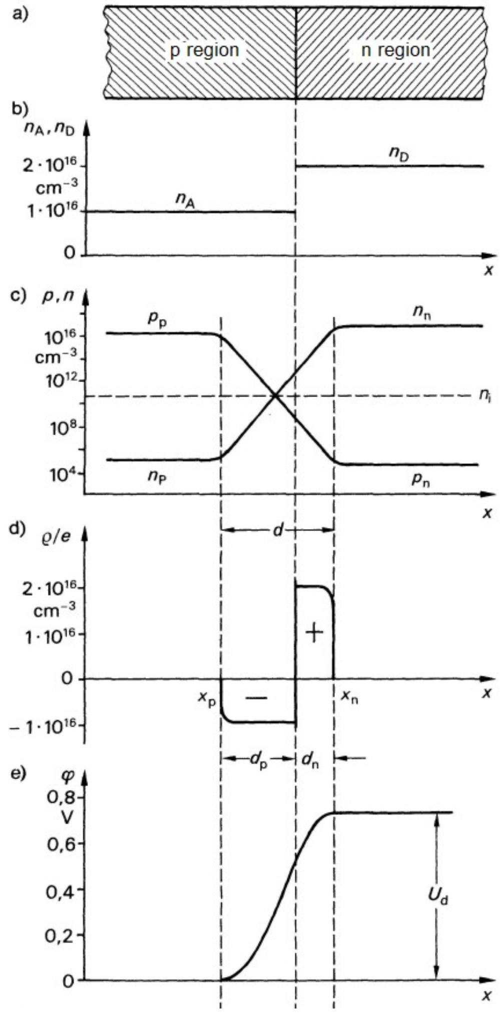


Fig. 2. Asymmetric p-n junstion in silicon based material: a) connection between p and n semiconductor type, b) acceptor concentration $n_A = 1 \cdot 10^{16}$ cm^{-3} and donor concentration $n_D = 2 \cdot 10^{16}$ cm^{-3}, c) free carrier concentration, d) volume charge density, e) potential curve [5]

While illuminating p-n junction with the correct wavelength, photons are absorbed and electron-hole pairs are generated (Figure 3a). The field separates both carriers in such a way that electrons reach n region and holes – p region (Figure 3b). It results in a potential difference, polarizing the junction in the conducting direction. The current-voltage characteristic is given by the diode equation, in which I is a current that would flow through p-n junction under the influence of the photoelectric voltage U.

$$I = I_0 [\exp(\frac{eU}{kT}) - 1] \quad (1)$$

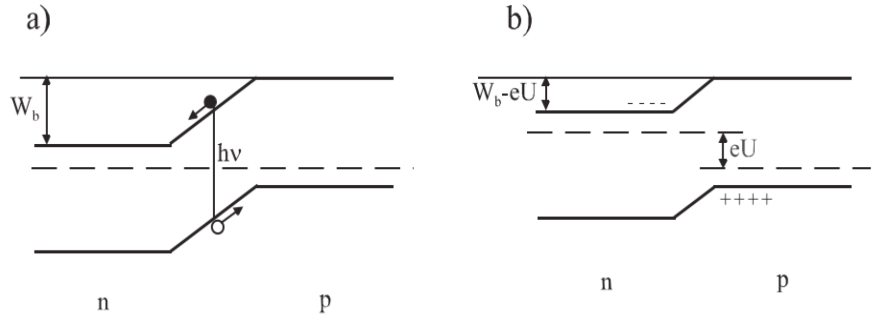


Fig. 3. Photovoltaic voltage generation after illuminating p-n junction [5]

2.2. Parameters of the current-voltage characteristics

Current-voltage (I-U) characteristics of PV module is a graph of output current from the photovoltaic generator as a function of voltage, at a specified temperature and solar irradiance. Specific points of I-U curve are marked in Figure 4 and called as:

- open circuit voltage (U_{OC}) – voltage at the ends of open photovoltaic generator at specific temperature and solar irradiance,
- short circuit current (I_{SC}) – output current of the photovoltaic generator at the short-circuit conditions at specific temperature and solar irradiance,
- maximum power point (MPP) – such a point of which coordinates of voltage (U_{MPP}) and current (I_{MPP}) create a rectangle with the greatest possible area under the I-U diagram.

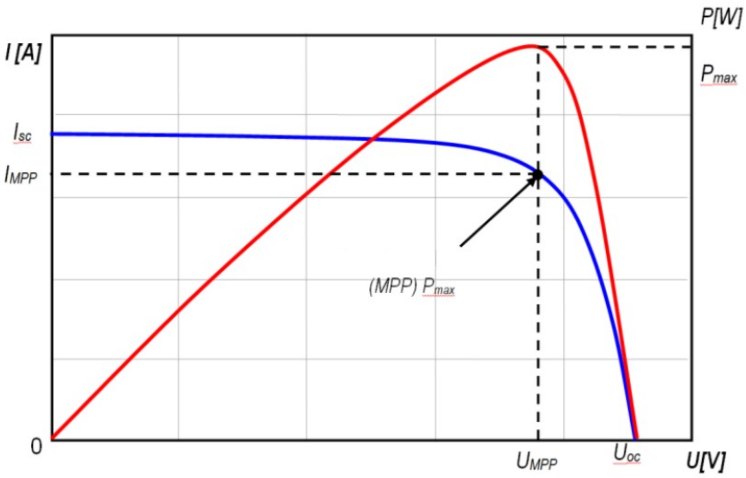


Fig. 4. Current-voltage characteristic and electric power generated by PV module as a function of voltage [6]

An important parameter in PV modules' usage for photovoltaic energetics is maximal output power, which can be obtained from module working under resistance load, R_{OPT}, that enables the rectangle under I-U curve to have the greatest possible area. The point of intersection of such a rectangle with the I-U curve is defined as maximum power point (P_{MPP}). Resistance load R for each solar cell circuit or PV module circuit should be adjusted in such a way that power generated reaches maximum value $P = P_{MPP}$.

$$P_{MPP} = I_{MPP} \cdot U_{MPP} \tag{2}$$

The fill factor (FF) for current-voltage characteristics is a parameter defining quality of solar cell or PV module and can be stated with equation:

$$FF = \frac{U_{MPP} \cdot I_{MPP}}{U_{OC} \cdot I_{SC}} \tag{3}$$

Solar irradiance has a determining influence on the course of the I-U curve and maximum power point value (Figure 5). Short circuit current increases in direct proportion to the solar irradiance reaching PV module's surface. Efficiency of the photovoltaic conversion is calculated on the basis of I-U characteristic evaluated under constant irradiance:

$$\eta = \frac{I_{MPP} \cdot U_{MPP}}{E \cdot S} \cdot 100\,\% \quad , \tag{4}$$

where:

S – area of solar cell or PV module [m^2],

E – solar irradiance [W/m^2].

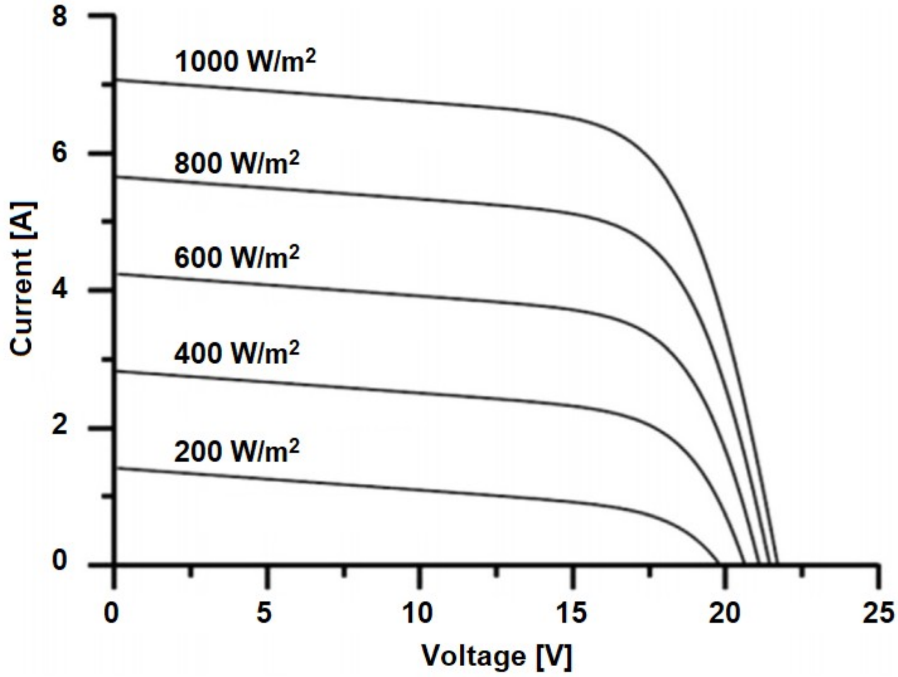


Fig. 5. I-U characteristics for PV installation working under different solar irradiance values [7]

Temperature of solar cells and PV modules during their work depends on solar irradiance value, wind speed, ambience temperature, thermal properties of installation components. It can rise above 70°C just by irradiating the surface with over 750 W/m^2 [8]. For instance, working temperature for a building integrated PV system mounted on the rooftop reaches 30°C, when the ambient temperature is 10,9°C and solar irradiance 381 W/m^2 [8]. Open circuit voltage is the main issue responsible for the loss in PV module efficiency (Figure 6). Slight increase of short circuit current does not compensate this reduction. As a result of elevated temperature of solar cells, less electrical power is generated, therefore photovoltaic conversion is declining.

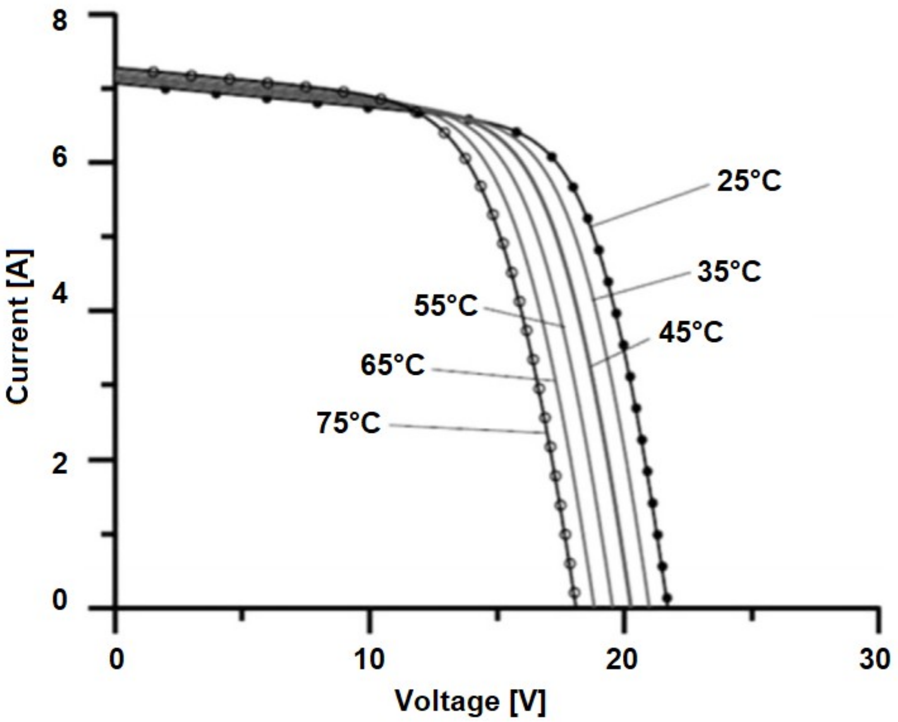


Fig. 6. Influence of solar cells' temperature on PV module's I-U characteristic [7]

2.3. Connecting the PV modules

the most common way of connecting PV modules is series connection, however there are also parallel, series-parallel, bridge-linked (BL), total cross-tied (TCT) and honeycomb (HC) connections (Figure 7). It should be noted that all modules in a string ought to have the same parameters. Once the work of one component undergoes degradation, the whole string is affected.

In a series connection current flow in each solar cell is the same, but voltages add up (Figure 8). In a parallel connection voltage is constant, but currents going into the nod add up (Figure 9).

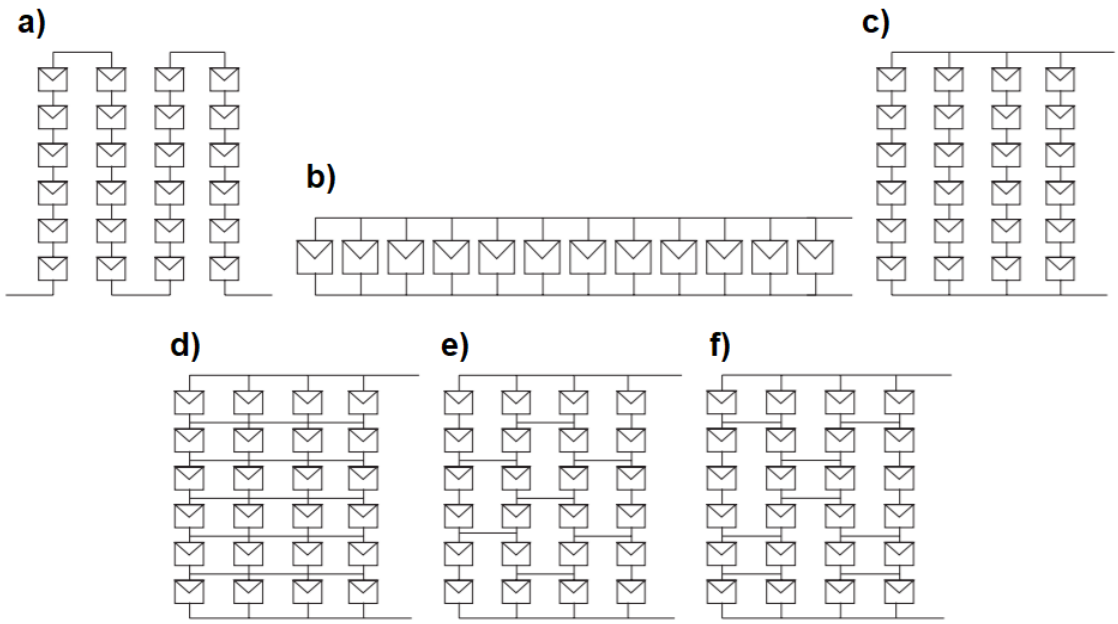


Fig. 7. Connection types for PV modules a) series, b) parallel, c) series-parallel, d) TCT, e) BL, f) HC [9]

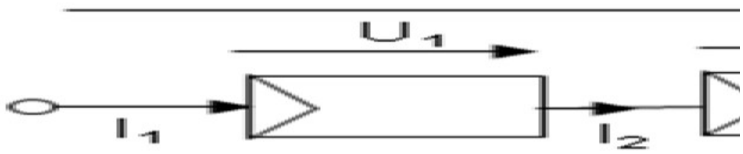


Fig. 8. PV modules connected in series [10]

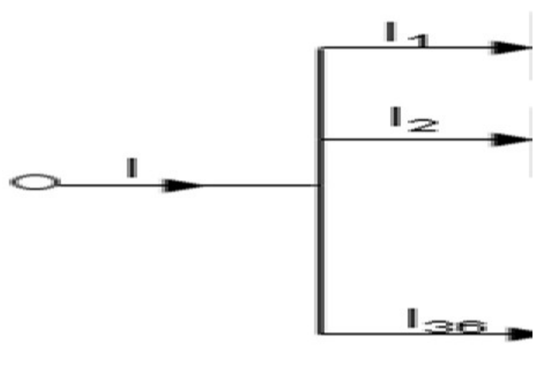


Fig. 9. PV modules connected in parallel [10]

Figure 10 exhibits exemplary current-voltage characteristics for PV installations connected respectively – in series (Figure 10a) and in parallel (Figure 10b).

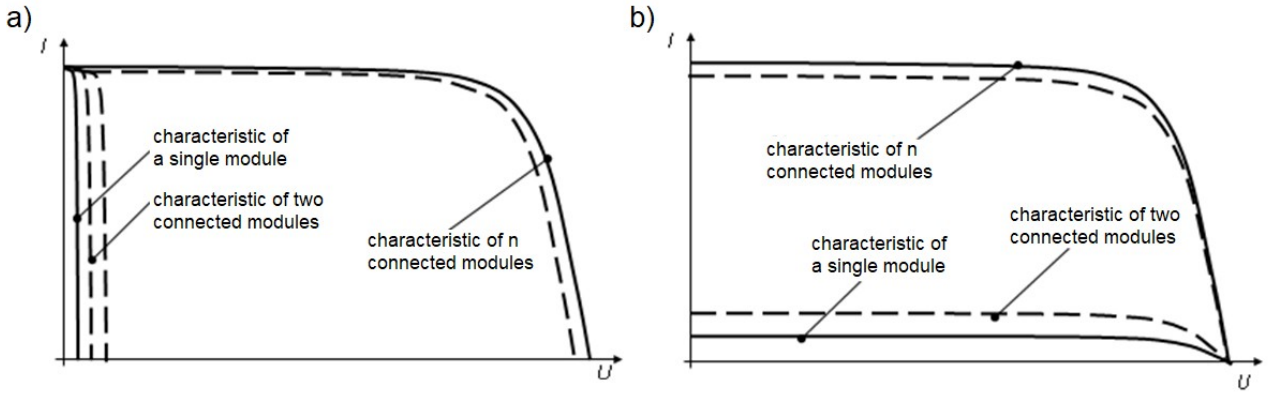


Fig. 10. I-U characteristic for PV installation consisting of n PV modules connected a) in series, b) in parallel [10]

Series-parallel connection is a combination of series connection and parallel connection, which is shown in Figure 11 and Figure 12.

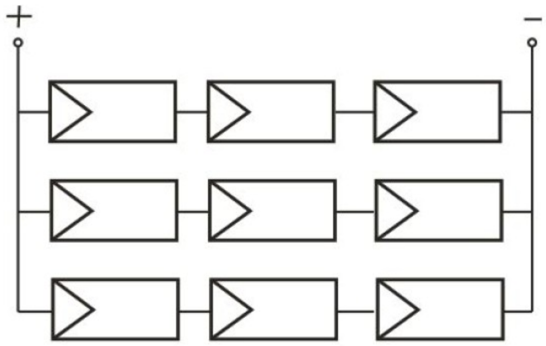


Fig. 11. PV modules connected in series-parallel [11]

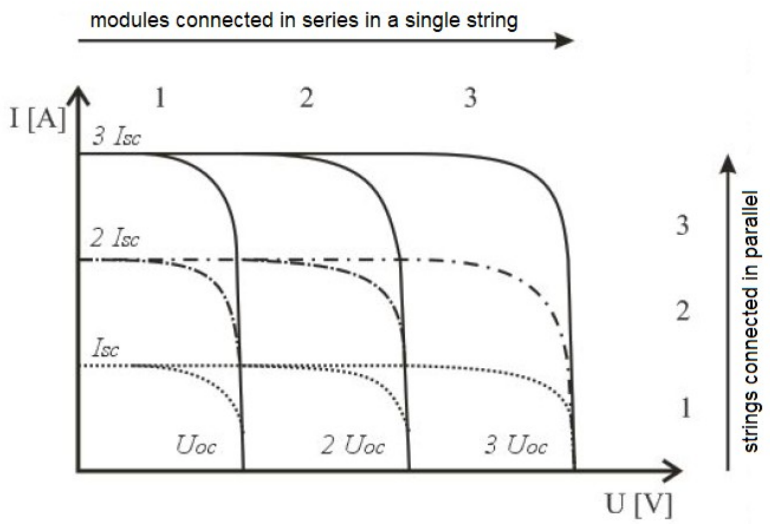


Fig. 12. I-U characteristic for PV installation consisting of n PV modules connected in series-parallel [11]

Objective of the project:

- obtaining the knowledge on how such factors as temperature, solar irradiance, tilt angle and connection type influence the expected energy yield from PV modules

Set of exercises and experiments to carry out as preparation for the project:

1. Measuring part

A. Investigating the impact of solar irradiance, tilt angle, temperature and connection type on working parameters and efficiency of PV modules.

B. Comparing results obtained from experiment carried out in laboratory conditions to the product data sheet.

C. Investigating the impact of ambient factors on working parameters and efficiency of PV modules in external conditions.

D. Comparing data obtained from Fronius system connected to PV installation integrated with Chemistry C building to data generated from PV-GIS program.

2. Design part

A. Designing PV installation that consists of 8 BEM-270 modules connected in one of four possible connection variants, while taking account of tilt angle, azimuth and surface area.

B. Analysing the expected energy yield for the above mentioned PV installation project.

C. Comparing the expected energy yield of proposed PV installation with data generated by Fronius as well as data calculated by PV-GIS system.

3. Measuring part

3A. PV module tested in laboratory conditions

a) The first part of the exercise is based on carrying out measurements for a chosen PV module. Out of all modules available in the laboratory hall, one needs to be selected and placed on the hooks mounted on the measuring unit's frame. Main parameters of each module are listed in Table 1.

Tab. 1. PV modules available in the laboratory hall, with their parameters according to the manufacturer

l. p.	**module**	**P_P [W_P]**	**U_{OC} [V]**	**I_{SC} [A]**	**U_{MPP} [V]**	**I_{MPP} [A]**	**length [mm]**	**width [mm]**
1	ATS 18-4528-FLEX	18	23,70	0,99	19,40	0,92	450	280
2	BEM 270	270	35,75	9,42	30,00	9,00	986	1634
3	ET-M53690WW (L)	90	21,98	5,54	18,25	4,93	545	1205
4	ET-M53690WW (P)	90	21,98	5,54	18,25	4,93	545	1205
5	GT-70PBX	70	21,63	4,09	17,13	4,87	668	895
6	SF 115/12-110	110	21,30	7,55	16,61	6,62	669	1491
7	SOLARA SM 60 M	15	22,60	1,10	19,00	0,94	250	620

Then, the module is connected to the measuring unit and rheostat in such a way as shown in Figure 13. If it turns out that cables from the module are to short, they should be extended with additional cables placed on the right side of the frame. Values of resistance that need to be measured in order to obtain I-U characteristic are included in a table attached to the project instruction (Appendix 1). All of the current and voltage values are displayed on the measuring unit.

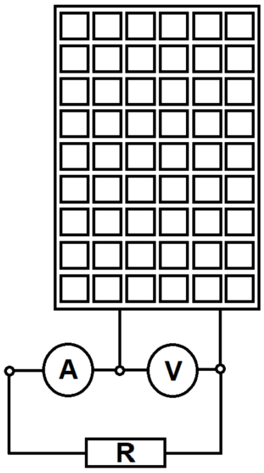


Fig. 13. PV module connected to measuring unit and rheostat

Open circuit voltage and short circuit current are measured according to the connection scheme in Figure 14.

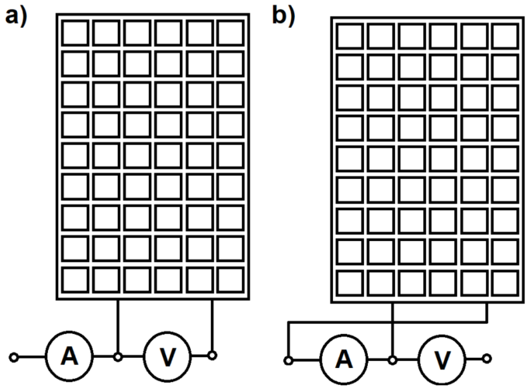


Fig. 14. Connection scheme for carrying out the measurement of a) open circuit voltage, b) short circuit current

b) Carry out measurements of voltage and current, open circuit voltage and short circuit current under three different irradiance conditions, namely 300 W/m^2, 500 W/m^2 and 800 W/m^2, while keeping constant temperature value 30°C. It should be noted that the increase of temperature causes decrease in open circuit voltage. The values ought to be taken from the 29 – 31°C range, which means that there are a few pauses during whole measurement, because the module need to cool down. Temperature measurement is taken with pyrometer in few points on the module surface. The desired value of irradiance is obtained by adjusting the distance between lamps and measuring unit, which should be noted in the project. To check if irradiance is indeed correct, few evenly distributed points on the module surface need to be measured with pyranometer and the results averaged.

c) Next, carry out measurements of voltage and current, open circuit voltage and short circuit current under three different temperature conditions, namely 30°C, 40°C and 50°C, while keeping constant irradiance value 800 W/m^2. There is 1°C deviation permitted for each temperature during the whole measurement.

d) Carry out measurements of voltage and current, open circuit voltage and short circuit current under four different PV module tilt angles α = 90°, 70°, 60°, 40°. Module needs to be tilted by the requested angle, as seen in the Figure 15. Irradiance value is measured in the same way as in previous exercises, namely – take the average of few irradiance values measured in evenly distributed points.

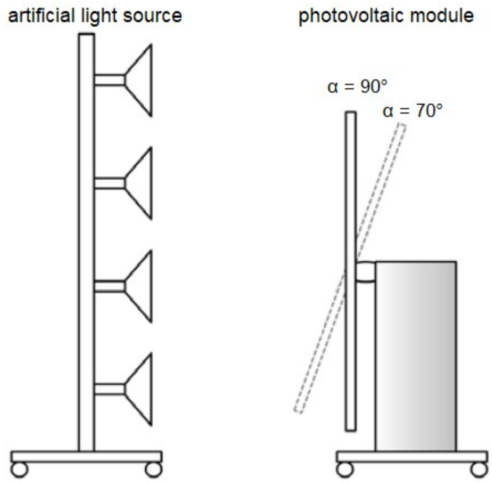


Fig. 15. Tilt angle of PV module [8]

e) For each measurement plot current-voltage characteristic and graph of power in the function of voltage. All of the curves mandatory for this part of project are listed in Table 2. Analyse obtained values, calculate fill factor FF, maximum power point P_{MPP} and efficiency η.

Tab. 2. Graphs of current as a function of voltage and power as a function of voltage that are requested in subparagraph A of the measuring part

<table>
<tr><th>graph</th><th>α [°]</th><th>T [°C]</th><th>E [W/m²]</th></tr>
<tr><td rowspan="3">I(U)
P(U)</td><td rowspan="3">90</td><td rowspan="3">30</td><td>300</td></tr>
<tr><td>500</td></tr>
<tr><td>800</td></tr>
<tr><td rowspan="3">I(U)
P(U)</td><td rowspan="3">90</td><td>30</td><td rowspan="3">800</td></tr>
<tr><td>40</td></tr>
<tr><td>50</td></tr>
<tr><td rowspan="4">I(U)
P(U)</td><td>90</td><td rowspan="4">30</td></tr>
<tr><td>70</td></tr>
<tr><td>60</td></tr>
<tr><td>45</td></tr>
</table>

f) Second part of the experiment consists in measuring voltages, currents, open circuit voltage and short circuit current for ET M 53690 modules in series connection (Figure 16a) and parallel connection (Figure 16b), while maintaining constant tilt angle α = 90°, as well as temperature 30°C. This module already has built in temperature sensor, so after heating it to 31°C measurement needs to be paused and resumed after temperature drops to at least 29°C.

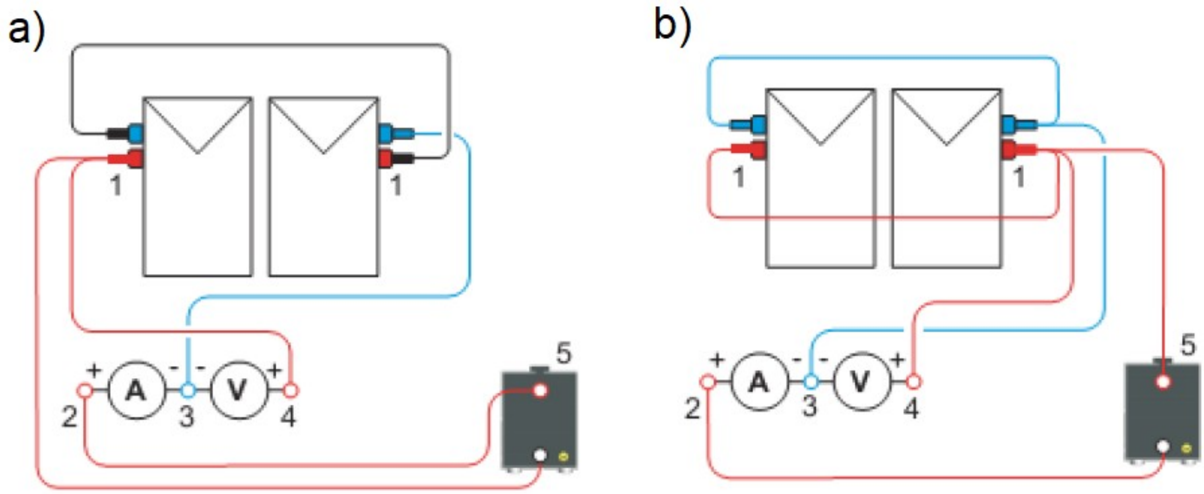


Fig. 16. Connecting PV modules a) in series, b) in parallel [8]

Draw current-voltage characteristic and graph of power in the function of voltage for each of the connection. Analyse results, calculate fill factor FF, maximum power point P_{MPP} and efficiency η.

Present conclusions from both parts of the experiment. They should include the discussion of impact from different external factors, such as irradiance, temperature, tilt angle and connection type, on working parameters of PV module and its efficiency.

3B. Comparing experiment results with product data sheet

a) Search the Internet in order to find a product data sheet for PV module chosen in first exercise in subparagraph 3A. Parameters in the sheet are determined for measurement in standard test conditions (STC). If the manufacturer does not provide direct efficiency value for PV module, it can be calculated from formula (1) and (2).

$$\eta = \frac{P_{MPP}}{E \cdot S} \cdot 100\% \tag{1}$$

$$P_{MPP} = U_{MPP} \cdot I_{MPP} \tag{2}$$

The comparison of working parameters between measurement of the PV module in the laboratory hall and carried out by producer ought to include: U_{OC}, I_{SC}, U_{MPP}, I_{MPP}, P_{MPP}, FF, η. All of those values need to presented in the form of table (Table 3).

Tab. 3. Working parameters and efficiency for the same PV module but in different testing conditions

	U_{OC} [V]	I_{SC} [A]	U_{MPP} [V]	I_{MPP} [A]	P_{MPP} [W]	FF	η [%]
manufacturer							
laboratory hall							

b) Present conclusions, which should include differences between working parameters provided by the producer and real values obtained during the experiment in the laboratory hall. Comment on the disparities in accordance with the knowledge obtained during experiment as well as literature review carried out individually.

3C. PV module tested in external conditions

a) Prepare mobile measuring unit outside of the laboratory hall. Connect PV module BEM-270 to ammeter, voltmeter and rheostat (Figure 17).

b) Place the module in location given by the teacher. Carry out measurements of voltage and current, open circuit voltage and short circuit current under four different tilt angles α = 90°, 70°, 60°, 40° (Figure 18). Pyranometer should be used for irradiance measurement, and pyrometer for temperature measurement – in the same way as during previous exercises.

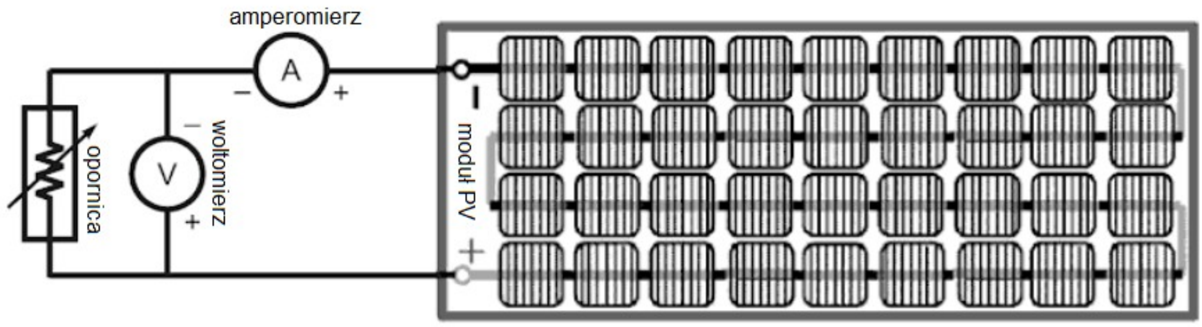


Fig. 17. PV module connection scheme [12]

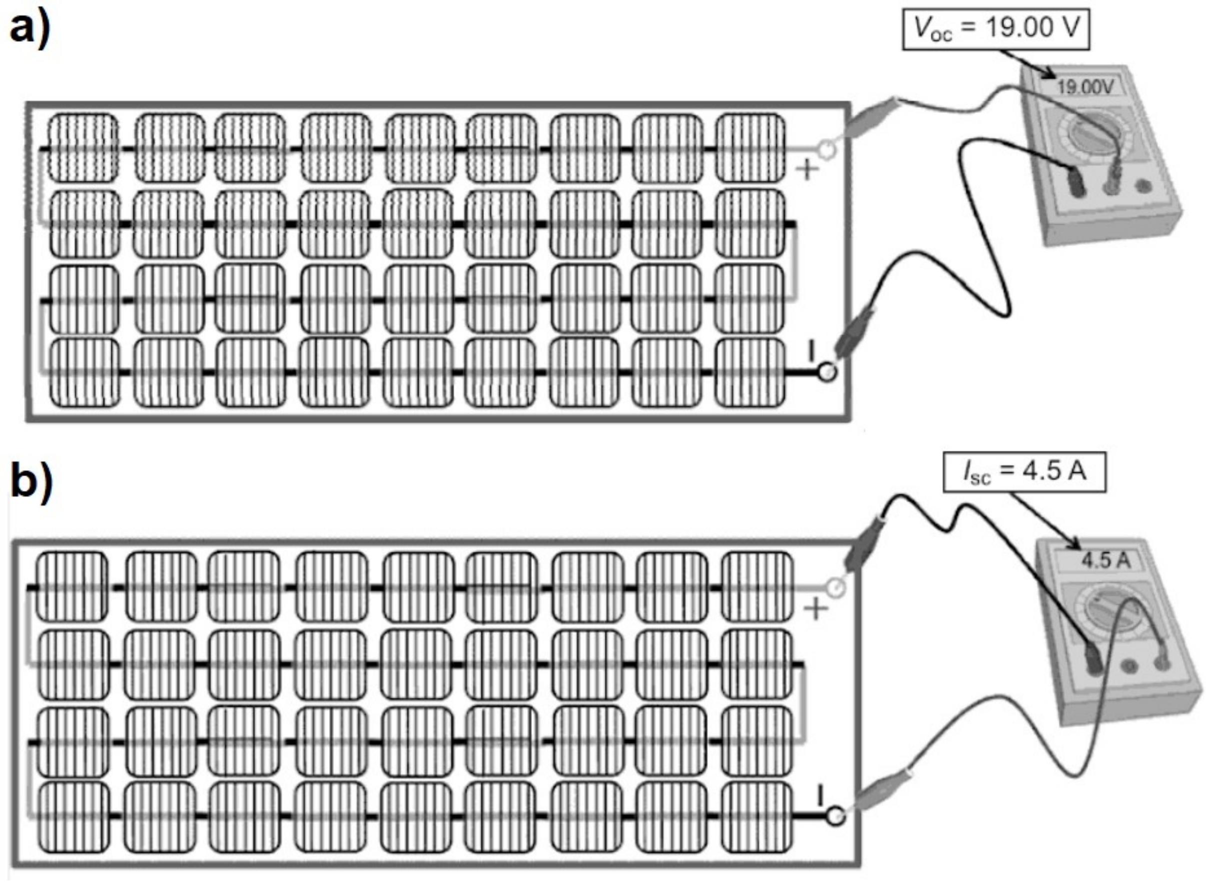


Fig. 18. Measurement of a) open circuit voltage, b) short circuit current [12]

c) Out of the obtained values I(U) and P(U) characteristics for four different tilt angles α should be made and presented in one graph. Analyse obtained results and calculate fill factor FF, maximum power point P_{MPP} and efficiency η for each tilt angle.

3D. Comparison of the data from PV installation with the data generated by PV-GIS

a) Review the contents of the exercise described in laboratory instruction 11_PV. It can be found on the website of Chemical Apparatus and Theory of Machines in the tabs “Teaching materials” → “Energy Sources Laboratory”. The instruction provides information on PV installation integrated with Chemistry building, which consists of 8 BEM-250 modules mounted at the tilt angle α = 90°.

b) By using the internet geographic information system website for photovoltaic installations (PV-GIS), collect data for average daily and monthly changes in solar irradiation, as well as average daily and monthly energy possible to generate (Figure 19 – Figure 23). When entering the data into PV-GIS, special attention should be paid to the geographical location of given installation (54° 22’ 13” N; 18° 37’ 18” E), tilt angle (90°), azimuth (-45°) and power installed (2 kWp).

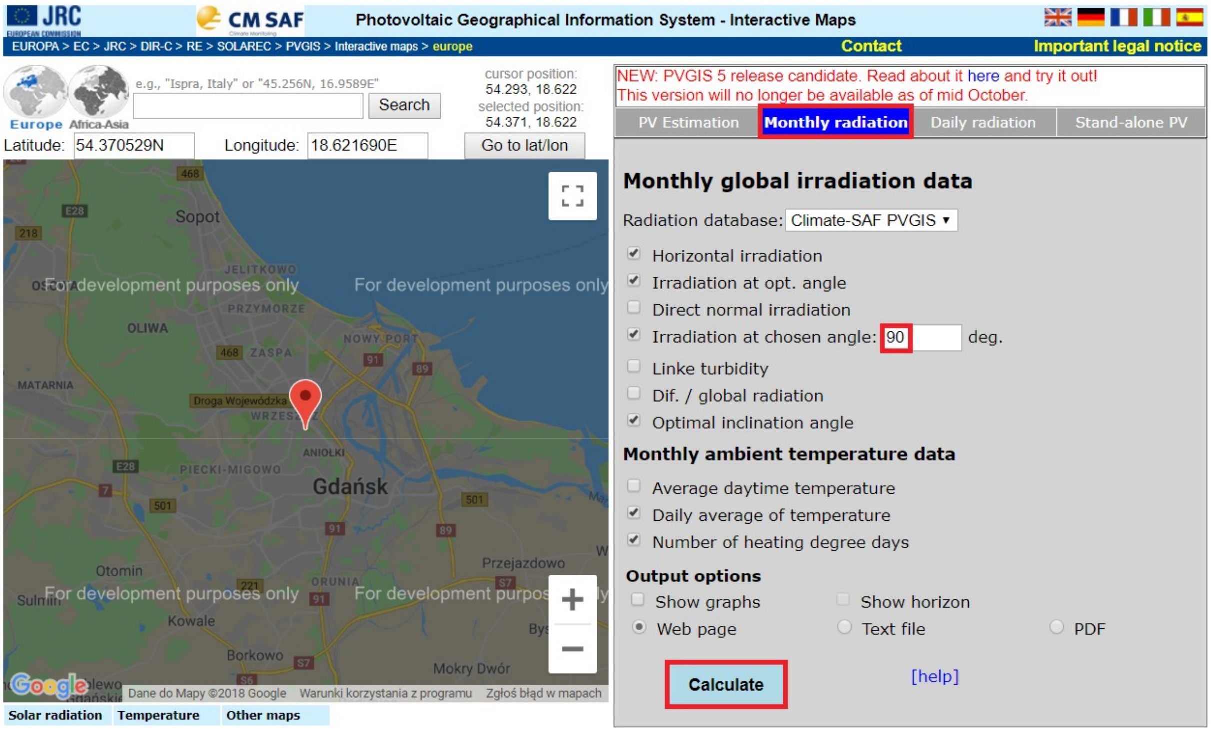


Fig. 19. Parameters entered into the PV-GIS system in order to calculate monthly change of solar irradiation [13]

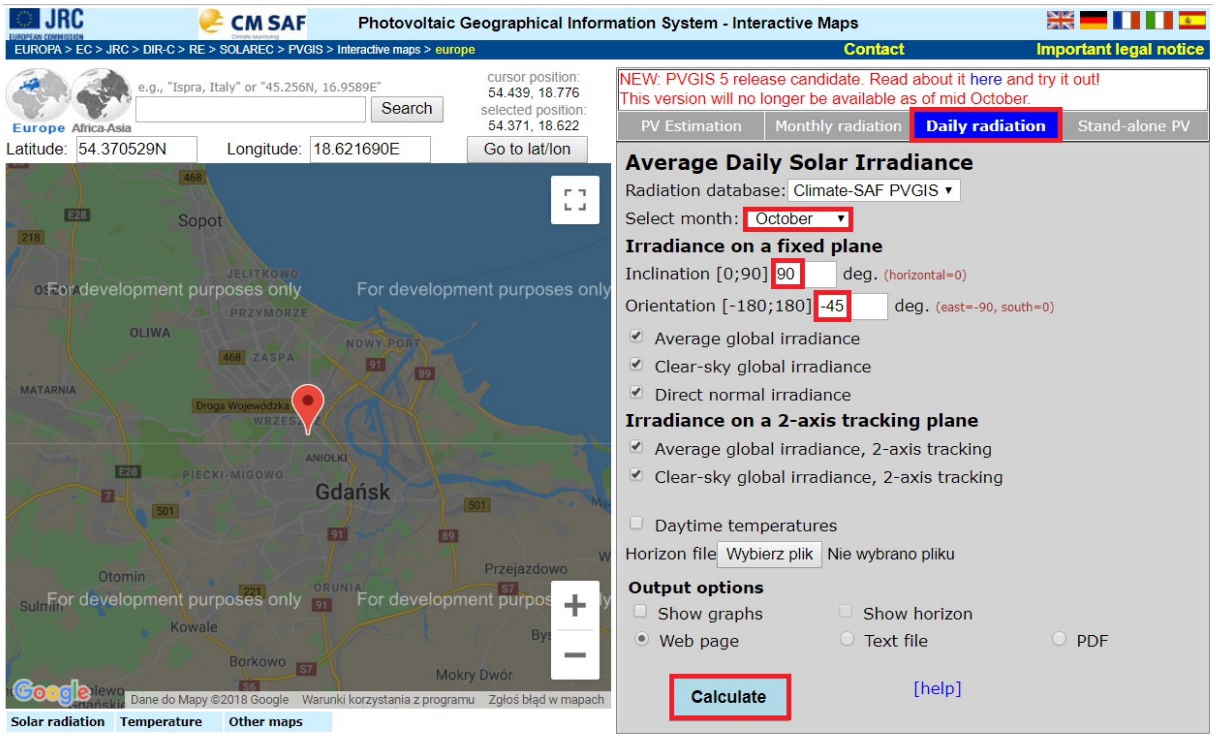


Fig. 20. Parameters entered into the PV-GIS system in order to calculate daily change of solar irradiation [13]

Monthly Solar Irradiation

PVGIS Estimates of long-term monthly averages

Location: 54°22'13" North, 18°37'18" East, Elevation: 23 m a.s.l.,

Solar radiation database used: PVGIS-CMSAF

Optimal inclination angle is: 39 degrees
Annual irradiation deficit due to shadowing (horizontal): 0.1 %

Month	H_h	H_{opt}	$H(90)$	I_{opt}	T_{24h}	N_{DD}
Jan	576	1030	1080	68	-2.9	555
Feb	1200	1880	1800	61	-1.8	507
Mar	2900	4130	3550	53	2.6	446
Apr	4520	5480	3860	40	7.4	252
May	5540	5780	3380	25	12.2	127
Jun	5810	5710	3090	17	15.6	55
Jul	5340	5350	3030	20	18.7	11
Aug	4500	5060	3290	33	18.3	41
Sep	3260	4340	3470	48	13.8	181
Oct	1800	2830	2670	60	8.5	342
Nov	688	1180	1200	66	4.8	500
Dec	422	826	907	72	0.2	594
Year	3060	3640	2610	39	8.1	3611

H_h: Irradiation on horizontal plane (Wh/m^2/day)

H_{opt}: Irradiation on optimally inclined plane (Wh/m^2/day)

$H(90)$: Irradiation on plane at angle: 90deg. (Wh/m^2/day)

I_{opt}: Optimal inclination (deg.)

T_{24h}: 24 hour average of temperature (°C)

N_{DD}: Number of heating degree-days (-)

Fig. 21. Monthly change in solar irradiation calculated by the PV-GIS system [13]

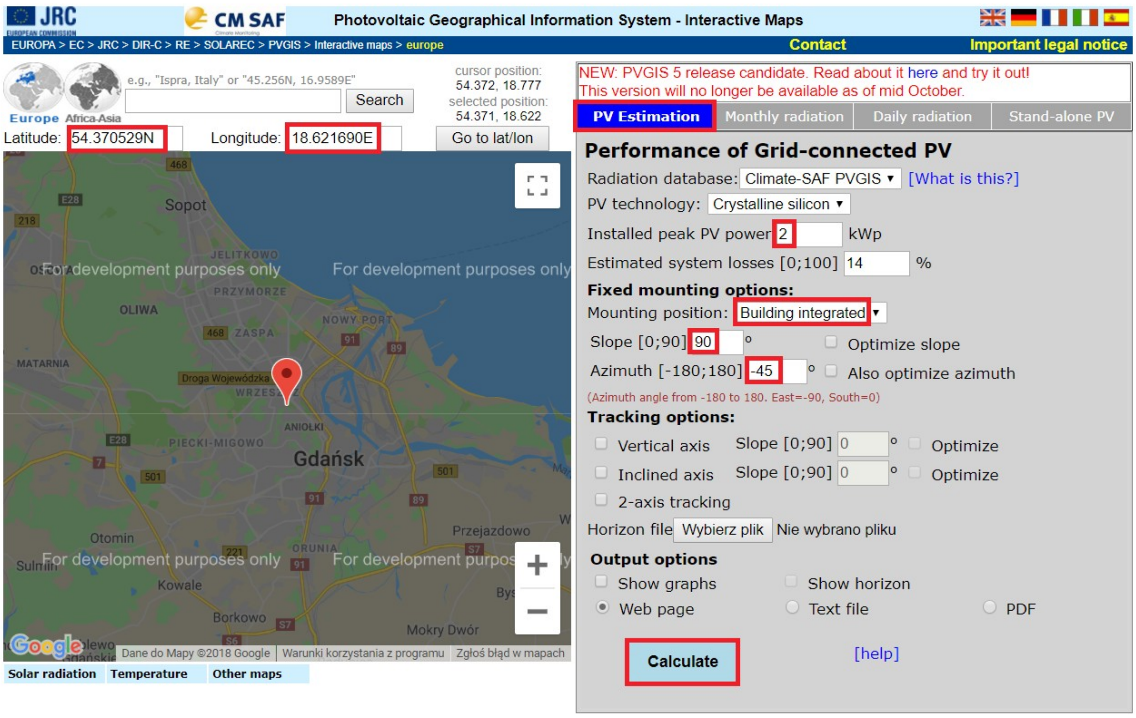


Fig. 22. Parameters entered into the PV-GIS system in order to calculate average daily and monthly energy possible to generate by photovoltaic installation [13]

Performance of Grid-connected PV

NOTE: before using these calculations for anything serious, you should read [this]

PVGIS estimates of solar electricity generation

Location: 54°22'13" North, 18°37'18" East, Elevation: 23 m a.s.l.,

Solar radiation database used: PVGIS-CMSAF

Nominal power of the PV system: 2.0 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 10.9% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 3.8%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 26.3%

Fixed system: inclination=90°, orientation=-45°				
Month	E_d	E_m	H_d	H_m
Jan	1.41	43.6	0.86	26.8
Feb	2.31	64.5	1.46	40.8
Mar	4.61	143	3.03	93.9
Apr	5.54	166	3.73	112
May	5.27	163	3.67	114
Jun	4.86	146	3.44	103
Jul	4.59	142	3.31	103
Aug	4.68	145	3.33	103
Sep	4.44	133	3.04	91.3
Oct	3.24	100	2.17	67.2
Nov	1.51	45.2	0.96	28.9
Dec	1.17	36.2	0.72	22.2
Yearly average	**3.64**	**111**	**2.48**	**75.5**
Total for year		**1330**		**906**

E_d: Average daily electricity production from the given system (kWh)
E_m: Average monthly electricity production from the given system (kWh)
H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)
H_m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

Fig. 23. PV-GIS system data set of daily and monthly energy possible to generate by photovoltaic installation [13]

c) By using the value of average daily irradiation H(90), calculate average monthly and daily energy produced by the photovoltaic installation, including 10% all-year-long efficiency. It should be noted that data from the example given below concern 2 kWp installation, and n means the number of days in chosen month.

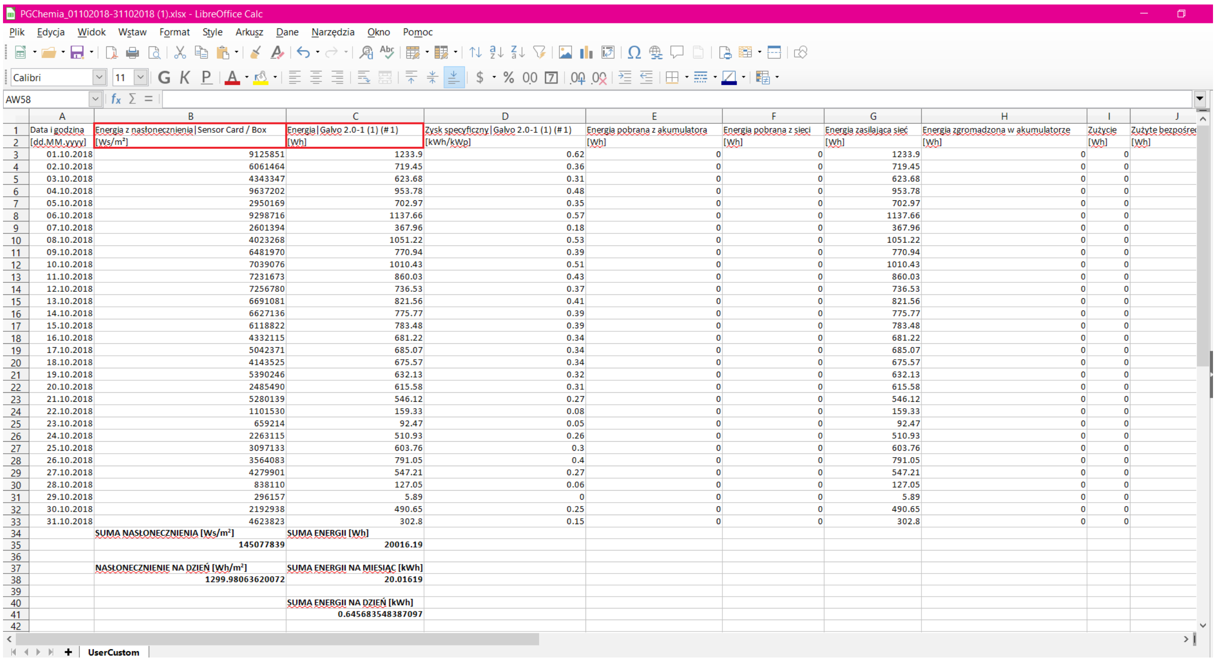
$$E_M = H(90) \cdot S \cdot 30 \cdot 10\% \tag{8}$$

$$E_D = \frac{E_M}{n} \tag{9}$$

$$E_M = 2670 \frac{Wh}{m^2 \cdot dzień} \cdot 12{,}89\, m^2 \cdot 30\, dni \cdot 10\% = 103\,241\, Wh = 103{,}24\, kWh$$

$$E_D = \frac{103{,}24\, kWh}{31} = 3{,}33\, kWh$$

Then, the same values should be calculated based on data received from the monthly rapport from Fronius application, provided that it is month with high irradiation values. In order to do that values from the "Irradiation" and "Energy" column should be summed and converted into kWh/m^2 and kWh (Figure 24).



PGChemia_01102018-31102018 (1).xlsx - LibreOffice Calc

	A	B	C	D	E	F	G	H	I	J
1	Data i godzina	Energia z nasłonecznienia | Sensor Card / Box	Energia | Galvo 2.0-1 (1) (# 1)	Zysk specyficzny | Galvo 2.0-1 (1) (# 1)	Energia pobrana z akumulatora	Energia pobrana z sieci	Energia zasilająca sieć	Energia zgromadzona w akumulatorze	Zużycie	Zużyte bezpośre
2	[dd.MM.yyyy]	[Ws/m²]	[Wh]	[kWh/kWp]	[Wh]	[Wh]	[Wh]	[Wh]	[Wh]	[Wh]
3	01.10.2018	9125851	1233.9	0.62	0	0	1233.9	0	0	
4	02.10.2018	6061464	719.45	0.36	0	0	719.45	0	0	
5	03.10.2018	4343347	623.68	0.31	0	0	623.68	0	0	
6	04.10.2018	9637202	953.78	0.48	0	0	953.78	0	0	
7	05.10.2018	2950169	702.97	0.35	0	0	702.97	0	0	
8	06.10.2018	9298716	1137.66	0.57	0	0	1137.66	0	0	
9	07.10.2018	2601394	367.96	0.18	0	0	367.96	0	0	
10	08.10.2018	4023268	1051.22	0.53	0	0	1051.22	0	0	
11	09.10.2018	6481970	770.94	0.39	0	0	770.94	0	0	
12	10.10.2018	7039076	1010.43	0.51	0	0	1010.43	0	0	
13	11.10.2018	7231673	860.03	0.43	0	0	860.03	0	0	
14	12.10.2018	7256780	736.53	0.37	0	0	736.53	0	0	
15	13.10.2018	6691081	821.56	0.41	0	0	821.56	0	0	
16	14.10.2018	6627136	775.77	0.39	0	0	775.77	0	0	
17	15.10.2018	6118822	783.48	0.39	0	0	783.48	0	0	
18	16.10.2018	4332115	681.22	0.34	0	0	681.22	0	0	
19	17.10.2018	5042371	685.07	0.34	0	0	685.07	0	0	
20	18.10.2018	4143525	675.57	0.34	0	0	675.57	0	0	
21	19.10.2018	5390246	632.13	0.32	0	0	632.13	0	0	
22	20.10.2018	2485490	615.58	0.31	0	0	615.58	0	0	
23	21.10.2018	5280139	546.12	0.27	0	0	546.12	0	0	
24	22.10.2018	1101530	159.33	0.08	0	0	159.33	0	0	
25	23.10.2018	659214	92.47	0.05	0	0	92.47	0	0	
26	24.10.2018	2263115	510.93	0.26	0	0	510.93	0	0	
27	25.10.2018	3097133	603.76	0.3	0	0	603.76	0	0	
28	26.10.2018	3564083	791.05	0.4	0	0	791.05	0	0	
29	27.10.2018	4279901	547.21	0.27	0	0	547.21	0	0	
30	28.10.2018	838110	127.05	0.06	0	0	127.05	0	0	
31	29.10.2018	296157	5.89	0	0	0	5.89	0	0	
32	30.10.2018	2192938	490.65	0.25	0	0	490.65	0	0	
33	31.10.2018	4623823	302.8	0.15	0	0	302.8	0	0	
34		SUMA NASŁONECZNIENIA [Ws/m²]	SUMA ENERGII [Wh]							
35		145077839	20016.19							
36										
37		NASŁONECZNIENIE NA DZIEŃ [Wh/m²]	SUMA ENERGII NA MIESIĄC [kWh]							
38		1299.98063620072	20.01619							
39										
40			SUMA ENERGII NA DZIEŃ [kWh]							
41			0.645683548387097							
42										

UserCustom

Fig. 24. Calculation example for October based on data received from Fronius application [13]

All of the obtained results – from Fronius application, PV-GIS system and calculations, are presented in table with a distinction being made between 2 kWp and 1 kWp installation. Because of weather limitations [8 – 11] values in Table 4 are based on chosen week and one single day, when PV installation produced the most energy.

Tab. 4. Average daily (H(90)) irradiation, maximum daily (E_D) and weekly (E_W) energy produced by photovoltaic installation in October. Day 16.10.2018 and week 15 – 21.10.2018 were chosen from Fronius application.

	For 2 kWp installation			**For 1 kWp installation**		
	Fronius	*PV-GIS*	*Calculations*	*Fronius*	*PV-GIS*	*Calculations*
H(90) [Wh/(m²·day)]	1299,98	2670,00	2670,00	1299,98	2670,00	2670,00
E_W [kWh]	20,02	100,00	103,24	10,01	50,00	51,62
E_D [kWh]	0,65	3,24	3,33	0,33	1,62	1,66

Comment the existing difference in irradiation and energy generation for Fronius and PV-GIS on the basis of weather conditions and values provided in the product data sheet. Additionally, carry out a comparative study of working parameters for BEM-250 and BEM-270 modules.

4. Design part

This part of the project focuses on designing small PV installation, consisting of 8 modules. Both knowledge from previous exercises and literature review carried out individually ought to be exercised. Teacher chooses PV module as well as connection type, which should be performed by student:

- only in series,
- only in parralel,
- series-parallel in configuration of 4 modules in series connected in parallel in 2 strings,
- series-parallel in configuration of 2 modules in series connected in parallel in 4 strings.

Prognosis of the installation parameters needs to be included. It is assumed that installation is mounted by the optimal tilt angle for Poland α = 35°.

5. Literature

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Appendix 1

Date:

PV module:

Temperature:

Irradiance:

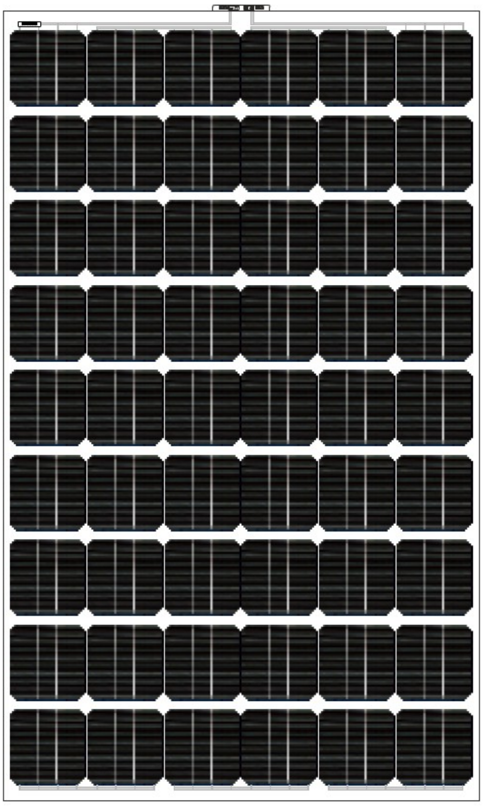
Surface area:

I_{SC} = U_{OC} =

R [Ω]	I [A]	U [V]	R [Ω]	I [A]	U [V]
0			32		
5			33		
6			34		
7			35		
8			36		
9			37		
10			38		
11			39		
12			40		
13			41		
14			42		
15			43		
16			44		
17			45		
18			46		
19			47		
20			48		
21			49		
22			50		
23			60		
24			70		
25			80		
26			90		
27			100		
28			200		
29			300		
30			400		
31			500		

Appendix 2

BRUK-BET SOLAR



BEM-250

- 12 year product warranty
- 25 year linear performance warranty
- 100 % electroluminescence inspection
- Guaranteed positive power tolerance
- Innovative solution: anti-reflective coating for high sunlight absorption
- High quality components
- Packing system to avoid micro cracks
- 4 busbars

ElektroEko Organizacja Odzysku Sprzętu Elektrycznego i Elektronicznego SA

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Appendix 2

TECHNICAL SPECIFICATIONS **BEM-250**

Electrical Characteristics	
Maximum power [Pmax]	250 Wp
Cells	Monocrystalline
Nr of cells	54
Short circuit current [Isc]	9,20 A
Open circuit voltage [Voc]	38,80 V
Maximum power current [Imax]	8,80 A
Maximum power voltage [Vmax]	28,45 V
Module efficiency	15,51 %
Maximum system voltage	1000 VDC
Tolerance	0 +4,99 Wp
Temperature coefficient current TcI	0,03 %/°C
Temperature coefficient voltage TcV	-0,31 %/°C
Power temperature coefficient TcP	-0,39 %/°C
NOCT (800 W/m2, 20°C, AM 1.5, 1m/s)	43±2 °C

Qualification test parameters	
Maximum load*	5400 Pa
Wind load	2400 Pa
Application class	A

Irradiance dependence

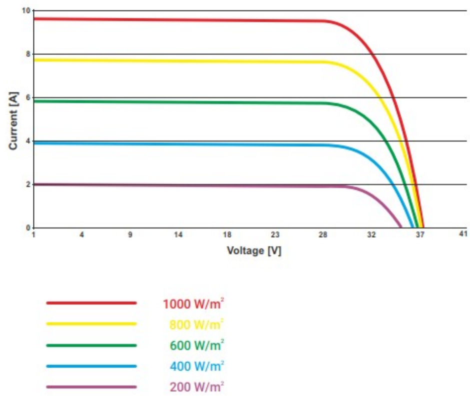
[W/m²]	1000	800	600	400	200
Isc	0 %	-19,60 %	-39,50 %	-59,20 %	-80,19 %
Voc	0 %	-1,38 %	-3,05 %	-5,90 %	-8,30 %

Physical characteristics	
Length	1634 mm
Width	986 mm
Thickness	8 mm
Weight	27 kg
Junction box	IP67
Bypass diodes	1
Reverse current protection	15 A

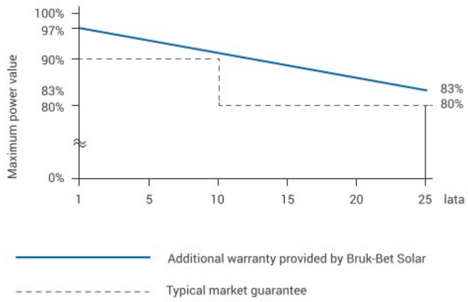
Packing

Packing method	Quantity	Transport
Cartoon 1,7x1,2 m	26 pieces/pallet	30 pallets/truck

CURRENT-VOLTAGE CHARACTERISTICS



BRUK-BET SOLAR WARRANTY



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