Dobór modułów PV i inwertera

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INNOVATIVE TRAINING OF FUTURE ENGINEERS
RESPONDING TO PROBLEMS OF CONTEMPORARY CITIES
2019-1-PL01-KA203-065654

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Selection of PV modules and inverter

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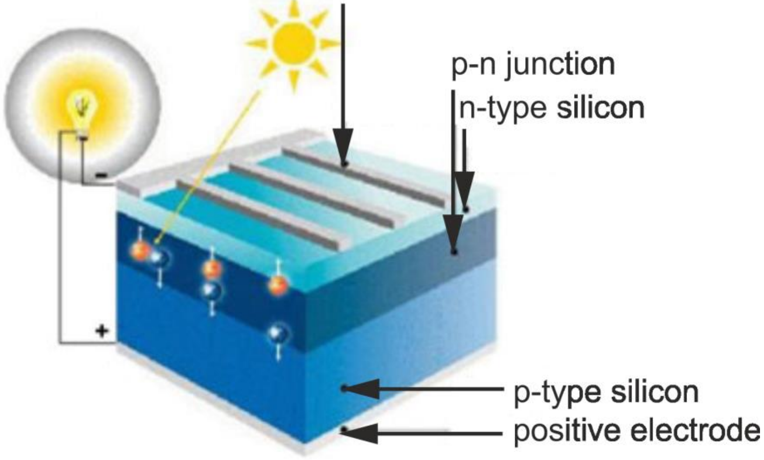
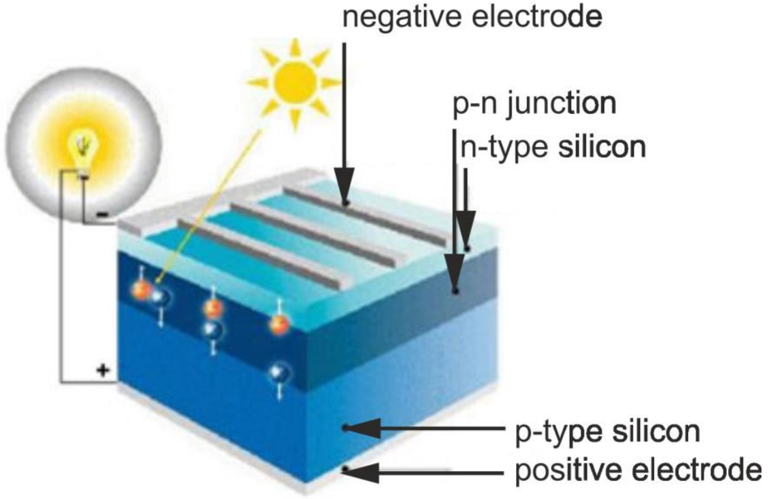
The principle of operation of a photovoltaic cell

- The principle of operation of photovoltaic panels is that the photovoltaic cells that make up the panels convert solar energy into electricity. For this purpose, a photon (that is, the minimum unit of light) falls on the silicon wafer which is the construction of the photovoltaic cell. The light unit is absorbed by the silicon and knocks the electron out of position forcing it to move. This movement is the flow of electric current. By using a p-n type semiconductor junction, it is possible to connect this process with the circulation of electrons in the power grid, thus transforming



The principle of operation of a photovoltaic cell

- A photovoltaic cell is made of two plates of appropriately modified silicon (Si). One is saturated with phosphorus (it is the so-called N-type semiconductor, N-type silicon), and the other with boron (P-type semiconductor, P-type silicon). Both plates have electrodes that connect them into a single circuit. The operation of the cell is therefore based on the principle of the P-N junction.



Types of photovoltaic cells - comparison

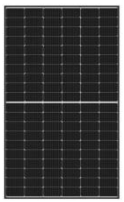
Monocrystalline panels. They are characterized by high efficiency, ranging from 14-20%, and the highest durability. They are made of one monolithic silicon crystal. Their color is dark and uniform. They have an octagonal shape, which allows us to save material during production. These panels are also characterized by a higher price on the market.

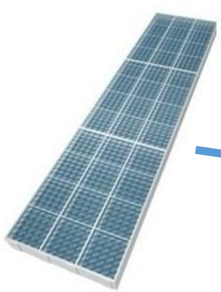
Polycrystalline panels. They are made of photovoltaic cells for which a large amount of silicon crystals is used. Unlike monocrystalline panels, they have a blue color and are not uniform. The square shape works best for these panels. The efficiency varies between 12-15% and the price is not high.

Amorphous silicon panels. They have the lowest efficiency, ranging from 6-10%, and also a very low price. They are characterized by a uniform brown color.

Concentrator photovoltaics (CPV) (also known as concentration photovoltaics) is a photovoltaic technology that generates electricity from sunlight. Unlike conventional photovoltaic systems, it uses lenses or curved mirrors to focus sunlight onto small, highly efficient, multi-junction (MJ) solar cells. In addition, CPV systems often use solar trackers and sometimes a cooling system to further increase their efficiency.

Types of photovoltaic cells



Solar Cell Type	Efficiency Rate	Advantages	Disadvantages
Monocrystalline Solar Panels (Mono-SI)	~20%	High efficiency rate; optimised for commercial use; high life-time value	Expensive
Polycrystalline Solar Panels (p-Si)	~15%	Lower price	Sensitive to high temperatures; lower lifespan & slightly less space efficiency
Thin-Film: Amorphous Silicon Solar Panels (A-SI)	~7-10%	Relatively low costs; easy to produce & flexible	shorter warranties & lifespan
Concentrated PV Cell (CVP)	~41%	Very high performance & efficiency rate	Solar tracker & cooling system needed (to reach high efficiency rate)

Connecting photovoltaic panels

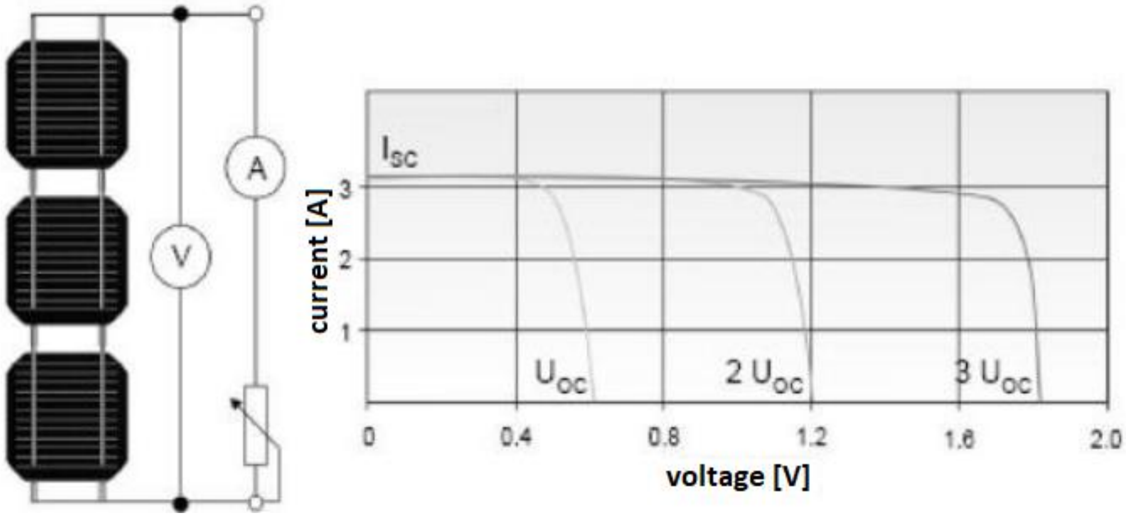
When carrying out the assembly of a photovoltaic installation, it is worth considering how to connect photovoltaic panels with each other. They can be connected in two ways, namely in parallel or in series. Both one way of joining the panels and the other have slightly different advantages that come from them.

In small installations, we use a series or parallel connection. The choice of connection of individual panels should be made at the stage of designing the installation. Serial connection is the most convenient for sizing and subsequent operation of the inverter, while parallel connection also has typical utility advantages. This type of panel connection results in greater efficiency when installed in a place that does not receive the maximum amount of sunlight. Therefore, the parallel connection undoubtedly increases the efficiency of the installation on cloudy days.

Connecting photovoltaic panels

Serial connection of photovoltaic panels

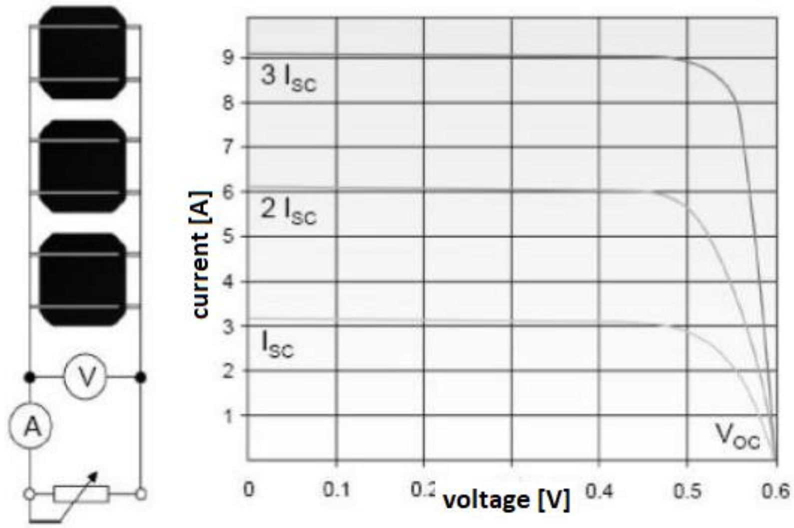
When connecting photovoltaic panels in series, you should know that the output voltage that will be supplied to the inverter will be the sum of the voltages of all individual panels. It is different when it comes to the amperage. The maximum amperage will be constant and exactly like a single panel. It is worth remembering that all installed photovoltaic panels should have the same maximum current. Failure to do so may result in unforeseen behavior of the inverter. Not only that, the failure of the photovoltaic installation during higher energy consumption is almost certain.



Connecting photovoltaic panels

Parallel connection of photovoltaic panels

Parallel connection of panels results in the fact that the total output voltage is always the same, while the maximum current is the sum of the individual panel intensities. Similar to series connection and parallel connection has its rules. Modules with different voltages cannot be connected to each other, which may result in a failure in the installation, destruction of the panel, or even damage to the inverter.



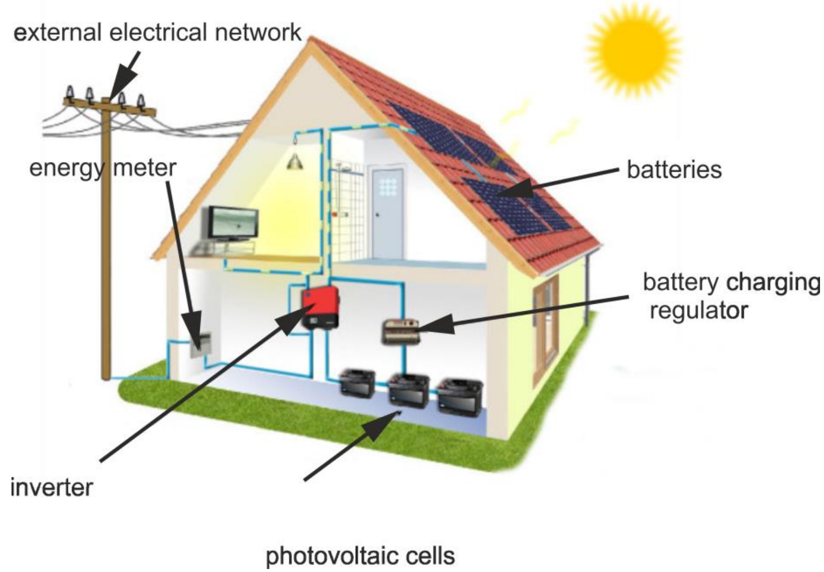
Connecting photovoltaic panels

Hybrid on-grid, off-grid photovoltaic installations with energy storage

If we decide to install a photovoltaic system, it is usually an on-grid system connected to an external power grid. An alternative is a hybrid on-grid or off-grid installation, with energy stored in batteries.

In the most popular on-grid installations, photovoltaic panels use the sun's rays and generate energy in the form of direct current. Then, inverters for photovoltaics turn it into alternating current, thus supplying all devices and equipment such as a computer, washing machine or refrigerator.

If we add batteries for energy storage to a PV installation, it can change to an on-grid hybrid system (still connected to the grid) or an off-grid system (working off-grid). The produced surpluses are then stored in special batteries and are not directed to the power grid (in the case of off-grid systems). On-grid hybrid systems, once the batteries are charged, can also channel surplus energy to the grid.



Connecting photovoltaic panels

Solar inverter

A solar inverter or PV inverter, is a type of power inverter which converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. It is a critical balance of system (BOS)–component in a photovoltaic system, allowing the use of ordinary AC-powered equipment. Solar power inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection.

Solar inverters may be classified into four broad types:

Stand-alone inverters, used in isolated systems where the inverter draws its DC energy from batteries charged by photovoltaic arrays. Many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source, when available. Normally these do not interface in any way with the utility grid, and as such, are not required to have anti-islanding protection.

Grid-tie inverters, which match phase with a utility-supplied sine wave. Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages.

Battery backup inverters, are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection.

Intelligent hybrid inverters, manage photovoltaic array, battery storage and utility grid, which are all coupled directly to the unit. These modern all-in-one systems are usually highly versatile and can be used for grid-tie, stand-alone or backup applications but their primary function is self-consumption with the use of storage.

Selection of the inverter for the PV installation

According to the applicable standards, only three-phase inverters must be used for installations above 3.68 kWp, otherwise the installation will not be connected to the power grid. In photovoltaic systems below 3kW, it is recommended to use a single-phase inverter for physical reasons. It is about the value of the voltage that is needed to generate a sine wave, in the case of single-phase inverters it is about 360V, i.e. as much as more or less generated by modules in a 3kW installation.

In cases where the power of the installation is in the range from 3 to 3.68 kW, it is possible to choose the inverter at the discretion. Single-phase inverters, in accordance with the requirements of the power company, can have a maximum power of up to 3.68 kW. The voltage corresponding to a three-kilowatt installation, usually consisting of 10 to 12 modules, ranging on average from 300 to 350 V, is sufficient for a single-phase inverter to achieve high efficiency. This type of inverter is connected to only one phase, so there is a choice of the most stable and optimal in terms of energy consumption. However, it is worth considering the installation of a three-phase inverter, which symmetrically distributes the power to each of the phases, which translates into the stability of the local network - it minimizes the risk of voltage fluctuations and allows the use of narrower wire cross-sections.

PV installation power	<3kW	3-4.6 kW	> 4.6 kW
Type of inverter	single phase inverter	single-phase or three-phase inverte	three phase inverter

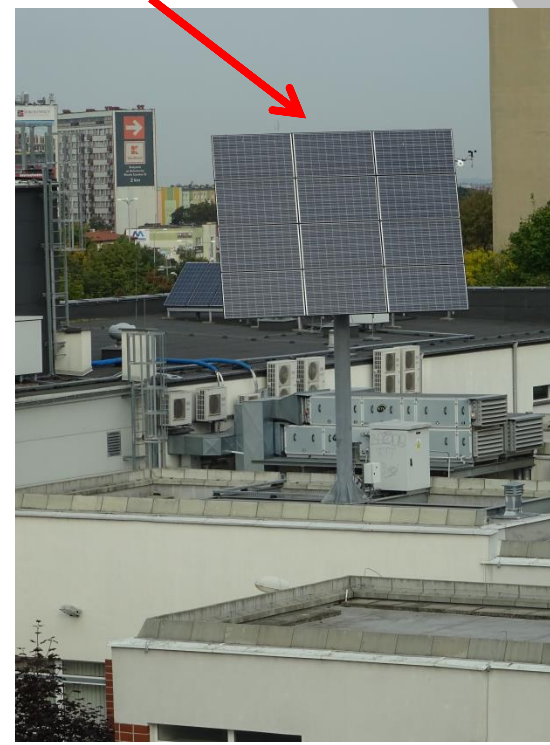
In Poland, it is assumed in practice that single-phase inverters are used up to 3kW.

Connecting photovoltaic panels

The angle of inclination of the photovoltaic panels

Regardless of whether the photovoltaic installation is installed on the roof or on the ground, great attention is paid to the angle of inclination of the PV panels. We try to arrange the modules so that they can receive the energy flowing from the sun as much as possible. In Poland, the optimal angle of inclination is considered to be 30 degrees, assuming that the panels face south.

Various methods of installing PV panels: on the ground, on a sloping roof, on a flat roof and with tracking.



Task 1

Selection of photovoltaic panels on the roof of the bus stop.

The main goal of the design task is to use the roof of a bus or train stop to install photovoltaic panels on it and produce electricity by a municipal company.
Due to the small area of the bus stop, it has been assumed that a single-phase inverter will be used, and the nominal power of the panels should not exceed 3kW.
The sentence assumes that the bus stop is not shaded, and the roof is 9m by 2m and is directed at an angle of 30 degrees to the south.

Possible locations of PV panels on the roofs of bus stops.

Task 1

Selection of photovoltaic panels on the roof of the bus stop.

The fields marked in green should be completed (file: *PV_tasks_student_name.xls*). An example for Białystok has been included in the *PV_tasks_example_Bialystok.xls* file.
The number of panels should be selected so that all PV panels can be installed on the roof of the bus stop and the total power of PV panels does not exceed 3000 W (3kW).
Below is an example of selecting and checking the dimensions of AS-6M120-HC-370W type PV panels.

Task 1										
Determining the number of panels based on the assumed power of the PV installation and the dimensions of the roof:										
P_{inst_max}	=	3000	W	assumed power of the PV installation						
L	=	9	m	roof length						
W	=	2	m	roof width						
The following type of PV panel was selected from the catalog:										
AS-6M120-HC-370W										
with the following parameters:										
Pmax	=	370	W	maximum power						
a	=	1.765	m	dimensions						
b	=	1.048	m	dimensions						
Determining the number of PV panels:										
$n=P_{inst\_max}/P_{max}$	=	3000.0	/	370	=	8.1	=	8.0	PV panels	
Checking the dimensions of the panels.										
The total length and width of all panels must not exceed the length and width of the roof, respectively.										
b*n<L	=>	1.048	x	8	=	8.384	<	9	m	ok
a<W	=>					1.765	<	2	m	ok
Actual maximum power of PV installation:										
$P_{inst\_max\_actual}=n*P_{max}$	=	8.0	x	370	=	2960	W=	2.96	kW	
Conclusions:										
Eight AS-6M120-HC-370W type PV panels were selected on the roof of the bus stop.										

Task 1

Selection of photovoltaic panels on the roof of the bus stop.

Below is an example of a website with parameters (dimensions, power) of the AS-6M120-HC-370W type PV panel.
http://www.weamerisolar.com/d/file/english/product/pro11555/2021/06-25/59fcfbe6b48e314826aafc861b2fe3ee.pdf

ELECTRICAL CHARACTERISTICS AT STC						
Maximum Power (P_{max})	355W	360W	365W	370W	375W	380W
Open Circuit Voltage (V_{OC})	41.0V	41.2V	41.4V	41.6V	41.8V	42.0V
Short Circuit Current (I_{SC})	11.09A	11.16A	11.23A	11.30A	11.37A	11.44A
Voltage at Maximum Power (V_{mp})	34.0V	34.2V	34.4V	34.6V	34.8V	35.0V
Current at Maximum Power (I_{mp})	10.45A	10.53A	10.62A	10.70A	10.78A	10.86A
Module Efficiency (%)	19.19	19.46	19.73	20.00	20.27	20.54
Operating Temperature	-40°C to +85°C					
Maximum System Voltage	1000V DC/1500V DC					
Fire Resistance Rating	Type 1(in accordance with UL1703)/Class C(IEC61730)					
Maximum Series Fuse Rating	20A					

STC: Irradiance 1000W/m^2, Cell temperature 25°C, AM1.5; Tolerance of Pmax: ±3%; Measurement Tolerance: ±3%

ELECTRICAL CHARACTERISTICS AT NOCT						
Maximum Power (P_{max})	26[illegible]W	267W	271W	275W	279W	283W
Open Circuit Voltage (V_{OC})	37.6V	37.8V	38.0V	38.2V	38.4V	38.6V
Short Circuit Current (I_{SC})	8.97A	9.03A	9.09A	9.15A	9.21A	9.27A
Voltage at Maximum Power (V_{mp})	31.0V	31.2V	31.4V	31.6V	31.8V	32.0V
Current at Maximum Power (I_{mp})	8.49A	8.56A	8.64A	8.71A	8.78A	8.85A

NOCT: Irradiance 800W/m^2, Ambient temperature 20°C, Wind Speed 1 m/s

MECHANICAL CHARACTERISTICS	
Cell type	Monocrystalline PERC 166*83mm
Number of cells	120 (6x20)
Module dimensions	1765x1048x35mm (69.49x41.26x1.38inches)

TEMPERATURE CHARACTERISTICS	
Nominal Operating Cell Temperature (NOCT)	43°C±2°C
Temperature Coefficients of P_{max}	-0.36%/°C
Temperature Coefficients of V_{oc}	-0.28%/°C

Task 2

Determination of the annual energy E from the selected PV installation on the roof of the bus stop.

Based on the location of the installation, the power of the selected panels from task 1, the roof inclination angle, the energy produced by the PV installations should be estimated.

Task 2

Determination of the annual energy E from the selected PV installation on the roof of the bus stop.

Location =>	Country:	Poland	City:	Bialystok

$E=E_s*c*P_{inst\_max\_actual}*d/STC$

Es	=	1070.9	kWh/m²/year	annual solar energy falling on the surface of the panels
c	=	1.1	-	

"c" is the coefficient that allows you to convert the annual solar energy data to the inclined surface of the photovoltaic generator (PV modules) from the annual solar energy data read from the map, which are for the horizontal surface.

Correction factor table, where the horizontal is the angle of deviation from the south, and the vertical angle of the roof slope.

$P_{inst\_max\_actual}$	=	2.96	kW
d	=	0.83	-

"d" is the coefficient of performance - an indicator that takes into account the level of losses in the photovoltaic system, calculated as 100% - the level of all losses. In general, in a photovoltaic installation we deal with the following losses:
cable losses - approx. 1%,
inverter losses - approx.
3–7%, module losses due to temperature - approx. crystalline silicon - the upper limit),
losses due to work at low intensity of solar radiation - about 1-3%,
losses due to shading, dirt - about 1-5% (in the case of non-optimal installations, they can be much higher),
losses due to from module current mismatch - about 1% (in the case of executive errors or having a damaged module in the installation - the losses can be much higher),
losses on bypass diodes - about 0.5%.

STC	=	1	kW/m²	(STC) - solar radiation intensity at which photovoltaic modules are tested, i.e. 1000 W/m² (1 kW/m²)

$E=E_s*c*P_{inst\_max\_actual}*d/STC=$ 1070.9x 1.1x 2.96x 0.83/ 1=

Conclusions:

The estimated annual energy obtained from the selected PV installation was: 2894.1 kWh

Task 2

Determination of the annual energy E from the selected PV installation on the roof of the bus stop.

The location as country and city should be taken according to the student's place of residence.

Task 2

Determination of the annual energy E from the selected PV installation on the roof of the bus stop.

Location =>	Country:	Poland	City:	Bialystok	

$E=E_s*c*P_{inst\_max\_actual}*d/STC$

Es	=	1070.9	kWh/m²/year	annual solar energy falling on the surface of the panels
c	=	1.1	-	

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Correction factor table, where the horizontal is the angle of deviation from the south, and the vertical angle of the roof slope.

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d	=	0.83	-

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losses due to from module current mismatch - about 1% (in the case of executive errors or having a damaged module in the installation - the losses can be much higher),

losses on bypass diodes - about 0.5%.

STC	=	1	kW/m²	(STC) - solar radiation intensity at which photovoltaic modules are tested, i.e. 1000 W/m² (1 kW/m²)

$E=E_s*c*P_{inst\_max\_actual}*d/STC=$ 1070.9x 1.1x 2.96x 0.83/ 1=

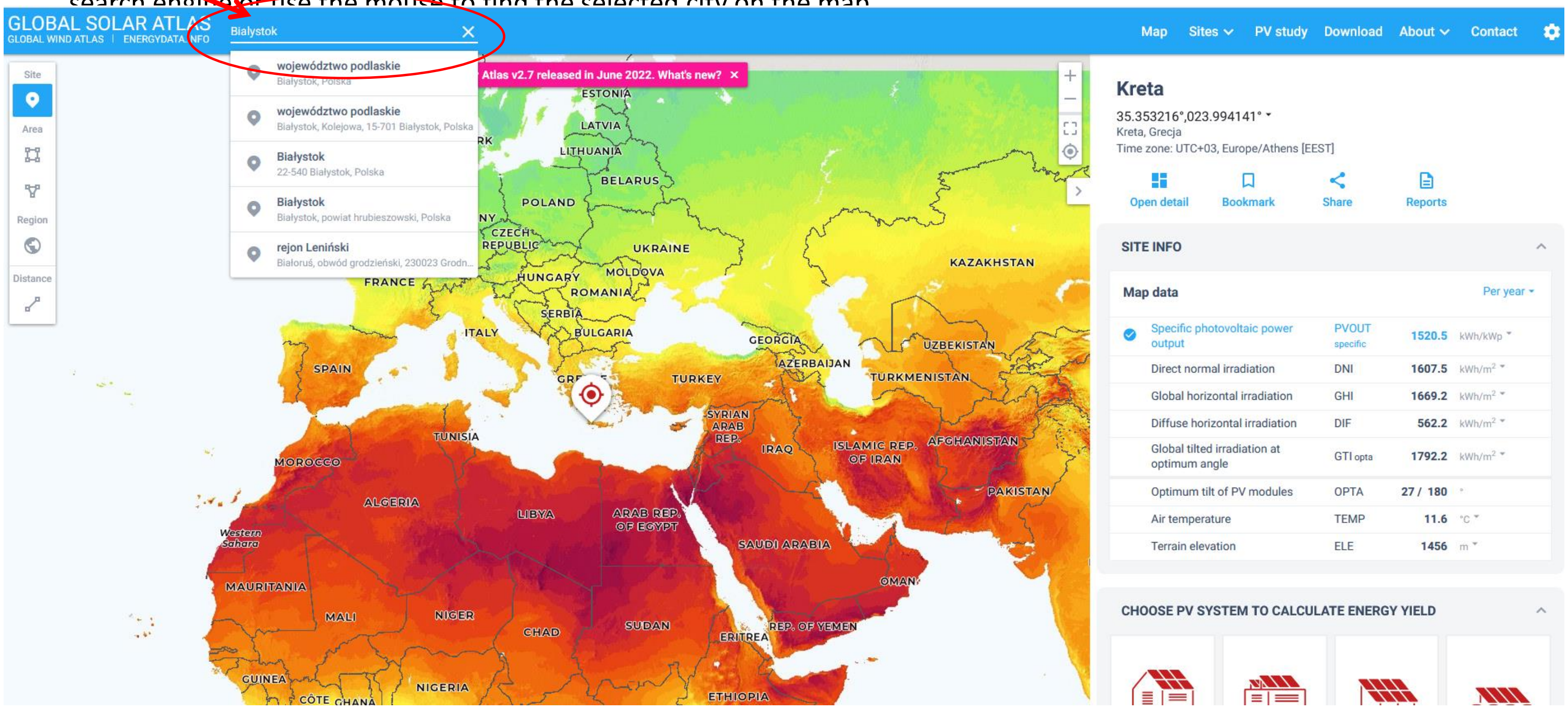
Conclusions:

The estimated annual energy obtained from the selected PV installation was: 2894.1 kWh

Task 2

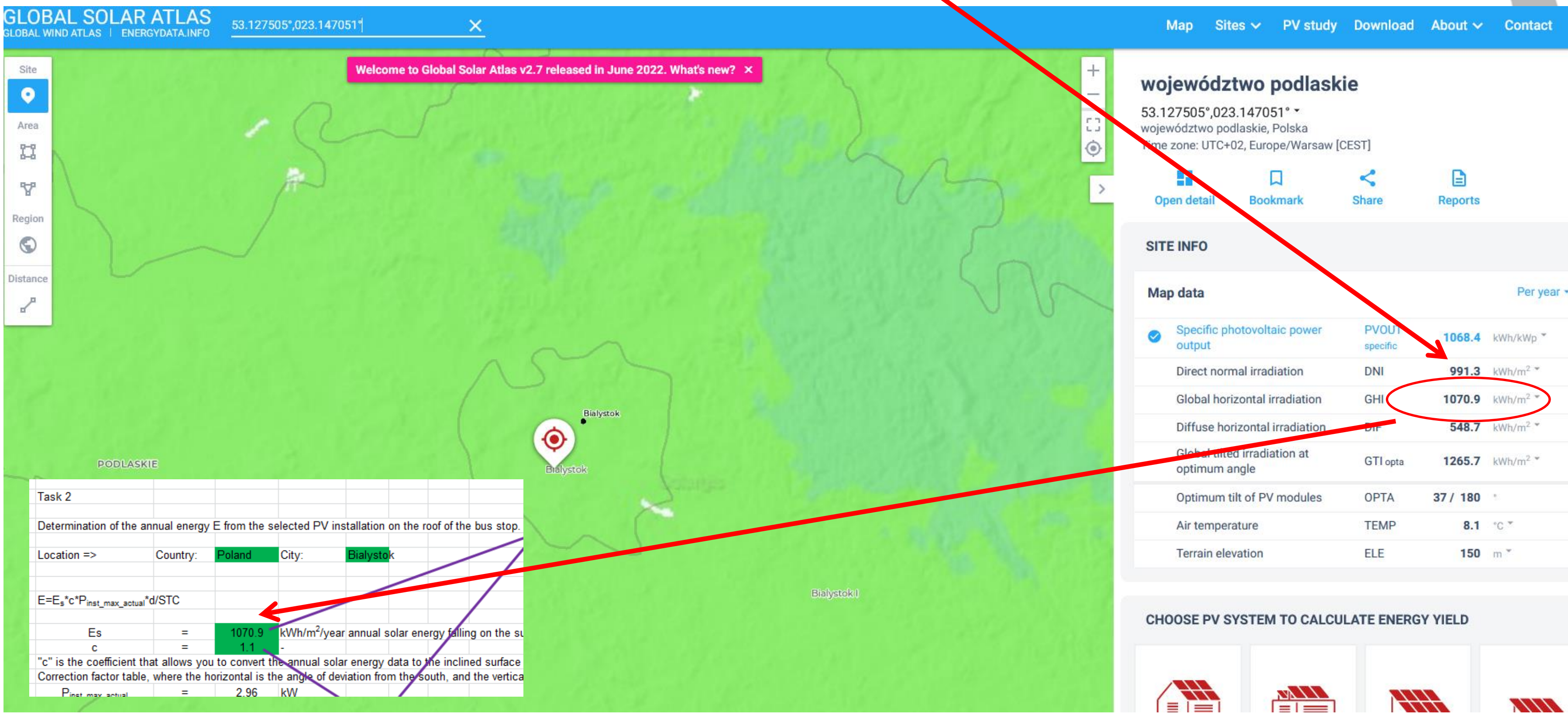
To read annual solar energy **Es** falling on the surface of the panels, refer to the Global Solar Atlas website (see other websites as well):
https://globalsolaratlas.info/map?c=31.765537,19.072266,4&s=35.353216,23.994141&m=site

1. The first step is to find the right location: country and city where the stop is located. You can enter the name of the city in the search engine or use the mouse to find the selected city on the map.



Task 2

2. After finding the selected city, on the left side read "Global horizontal irradiation" and enter the value into the Excel file.



Task 2

Determination of the annual energy E from the selected PV installation on the roof of the bus stop.

The "c" factor for the angle of the panels should be read from the table, where the horizontal angle of deviation from the south is given, and the vertical angle of the roof inclination (we assume that the roof inclination angle is 30 degrees and the deviation from the south is -35 degrees, these data can be changed if other values are given in the design).

Task 2

Determination of the annual energy E from the selected PV installation on the roof of the bus stop.

Location => Country: Poland City: Bialystok

$E=E_s*c*P_{inst\_max\_actual}*d/STC$

Es	=	1070.9	kWh/m²/year	annual solar energy
c	=	1.1	-	

"c" is the coefficient that allows you to convert the annual solar energy da to the inclined surface of the photovoltaic g are for the horizontal surface.

Correction factor table, where the horizontal is the angle of deviation from the south, and the vertical angle of the roof

$P_{inst\_max\_actual}$	=	2.96	kW
d	=	0.83	-

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losses due to from module current mismatch - about 1% (in the case of executive errors or having a damaged module in the inst
losses on bypass diodes - about 0.5%.

STC	=	1	kW/m²	(STC) - solar radiation

$E=E_s*c*P_{inst\_max\_actual}*d/STC=$ 1070.9x 1.1x

Kąt	-90	-85	-80	-75	-70	-65	-60	-55	-50	-45	-40	-35	-30	-25	-20	-15	-10	-5	0
0	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
5	1,00	1,00	1,00	1,01	1,01	1,01	1,02	1,02	1,02	1,03	1,03	1,03	1,03	1,03	1,03	1,03	1,04	1,04	1,04
10	0,99	1,00	1,01	1,01	1,02	1,02	1,03	1,04	1,04	1,05	1,05	1,05	1,06	1,06	1,06	1,06	1,07	1,07	1,07
15	0,98	0,99	1,00	1,01	1,02	1,03	1,04	1,05	1,05	1,06	1,07	1,07	1,08	1,08	1,09	1,09	1,09	1,09	1,10
20	[illegible]	0,98	1,00	1,01	1,02	1,03	1,04	1,05	1,06	1,07	1,08	1,09	1,09	1,10	1,10	1,11	1,11	1,11	1,01
25	0,96	0,97	0,99	1,00	1,02	[illegible]	[illegible]	1,06	1,07	1,08	1,09	1,10	1,10	1,11	1,12	1,12	1,12	1,12	1,12
30	0,94	0,96	0,98	1,00	1,01	1,03	1,04	1,06	1,07	1,08	1,09	1,10	1,11	1,12	1,12	1,13	1,13	1,13	1,13
35	0,93	0,95	0,97	0,99	1,00	1,02	1,04	1,05	1,07	1,08	1,09	1,10	1,11	1,12	1,12	1,13	1,13	1,13	1,13
40	0,91	0,93	0,95	0,97	0,99	1,01	1,03	1,04	1,06	1,07	1,09	1,10	1,10	1,11	1,12	1,12	1,13	1,13	1,13
45	0,88	0,91	0,93	0,96	0,98	1,00	1,01	1,03	1,05	1,06	1,07	1,09	1,10	1,10	1,11	1,11	1,12	1,12	1,12
50	0,87	0,89	0,92	0,94	0,96	0,98	1,00	1,01	1,03	1,04	1,06	1,07	1,08	1,09	1,09	1,10	1,10	1,10	1,11
55	0,85	0,87	0,89	0,92	0,94	0,96	0,97	0,99	1,01	1,02	1,04	1,05	1,06	1,07	1,07	1,08	1,08	1,08	1,08
60	0,82	0,85	0,87	0,89	0,91	0,93	0,95	1,00	0,98	1,00	1,01	1,02	1,03	1,04	1,05	1,05	1,05	1,06	1,06
65	0,80	0,82	0,84	0,86	0,88	0,90	0,92	0,94	0,95	0,97	0,98	0,99	1,00	1,01	1,02	1,02	1,02	1,02	1,02
70	0,77	0,79	0,81	0,83	0,85	0,87	0,89	0,91	0,92	0,93	0,95	0,96	0,97	0,97	0,98	0,98	0,99	0,99	0,99
75	0,74	0,76	0,78	0,80	0,82	0,84	0,86	0,87	0,89	0,90	0,91	0,92	0,93	0,93	0,94	0,94	0,94	0,95	0,95
80	0,71	0,73	0,75	0,77	0,79	0,80	0,82	0,83	0,85	0,86	0,87	0,88	0,89	0,89	0,89	0,90	0,90	0,90	0,90
85	0,67	0,69	0,71	0,73	0,75	0,77	0,78	0,79	0,81	0,82	0,83	0,83	0,84	0,84	0,85	0,85	0,85	0,85	0,85
90	0,64	0,66	0,68	0,69	0,71	0,72	0,74	0,75	0,76	0,77	0,78	0,79	0,97	0,79	0,80	0,80	0,80	0,80	0,80

Conclusions:

The estimated annual energy obtained from the selected PV installation was: 2894.1kWh

Task 2

Determination of the annual energy E from the selected PV installation on the roof of the bus stop.

The intensity of solar radiation at which the photovoltaic modules are tested, i.e. 1000 W / m2 (1 kW / m2), should be taken from the data of the selected collector.

Task 2

Determination of the annual energy E from the selected PV installation on the roof of the bus stop.

Location => Country: Poland City: Bialystok

$E=E_s*c*P_{inst\_max\_actual}*d/STC$

Es	=	1070.9	kWh/m2/year	a
c	=	1.1	-	

"c" is the coefficient that allows you to convert the annual solar energy data to the inclined surface (are for the horizontal surface.

Correction factor table, where the horizontal is the angle of deviation from the south, and the vertica

$P_{inst\_max\_actual}$	=	2.96	kW
d	=	0.83	-

"d" is the coefficient of performance - an indicator that takes into account the level of losses in the photovo the following losses:
cable losses - approx. 1%,
inverter losses - approx.
3–7%, module losses due to temperature - approx. crystalline silicon - the upper limit),
losses due to work at low intensity of solar radiation - about 1-3%,
losses due to shading, dirt - about 1-5% (in the case of non-optimal installations, they can be much higher),
losses due to from module current mismatch - about 1% (in the case of executive errors or having a damage
losses on bypass diodes - about 0.5%.

STC	=	1	kW/m2

$E=E_s*c*P_{inst\_max\_actual}*d/STC=$ 1070.9x

Conclusions:
The estimated annual energy obtained from the selected PV installation was: 2894.1 kWh

ELECTRICAL CHARACTERISTICS AT STC

Maximum Power (P_{max})	355W	360W	365W	370W	375W	380W
Open Circuit Voltage (V_{OC})	41.0V	41.2V	41.4V	41.6V	41.8V	42.0V
Short Circuit Current (Isc)	11.09A	11.16A	11.23A	11.30A	11.37A	11.44A
Voltage at Maximum Power (V_{mp})	34.0V	34.2V	34.4V	34.6V	34.8V	35.0V
Current at Maximum Power (I_{mp})	10.45A	10.53A	10.62A	10.70A	10.78A	10.86A
Module Efficiency (%)	19.19	19.46	19.73	20.00	20.27	20.54
Operating Temperature	-40°C to +85°C					
Maximum System Voltage	1000V DC/1500V DC					
Fire Resistance Rating	Type 1(in accordance with UL1703)/Class C(IEC61730)					
Maximum Series Fuse Rating	20A					

STC: Irradiance 1000W/m², Cell temperature 25°C, AM1.5; Tolerance of Pmax: ±3%; Measurement Tolerance: ±3%

ELECTRICAL CHARACTERISTICS AT NOCT

Maximum Power (P_{max})	263W	267W	271W	275W	279W	283W
Open Circuit Voltage (V_{OC})	37.6V	37.8V	38.0V	38.2V	38.4V	38.6V
Short Circuit Current (Isc)	8.97A	9.03A	9.09A	9.15A	9.21A	9.27A
Voltage at Maximum Power (V_{mp})	31.0V	31.2V	31.4V	31.6V	31.8V	32.0V
Current at Maximum Power (I_{mp})	8.49A	8.56A	8.64A	8.71A	8.78A	8.85A

NOCT: Irradiance 800W/m², Ambient temperature 20°C, Wind Speed 1 m/s

MECHANICAL CHARACTERISTICS

Cell type	Monocrystalline PERC 166*83mm
Number of cells	120 (6x20)
Module dimensions	1765x1048x35mm (69.49x41.26x1.38inches)

TEMPERATURE CHARACTERISTICS

Nominal Operating Cell Temperature (NOCT)	43°C±2°C
Temperature Coefficients of P_{max}	-0.36%/°C
Temperature Coefficients of V_{OC}	-0.28%/°C

Task 3

Selection of PV modules and inverter

The power of the PV generator determines the maximum allowable power value of the PV modules connected to the inverter. The nominal power on the AC (alternating current) side is always slightly lower and determines the maximum power of receivers that can be connected to the inverter, or the maximum amount of energy that can be fed into the grid.

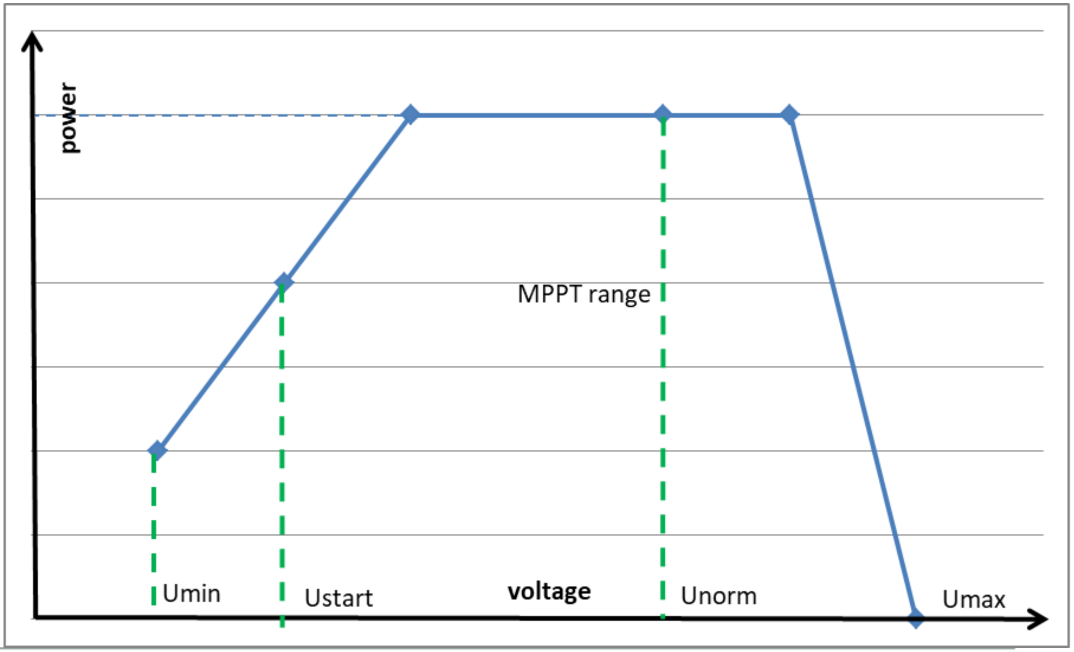
The power of the PV generator is always given for STC conditions, which are rarely achieved in practice. Throughout the year in Poland, energy of the order of 1000W/m^2 occurs only for a period of several to several hours, which is only about 2% of the total time of solar insolation of PV modules. In the remaining time, the insolation does not exceed the value of 700-850W/m^2. It follows that it is always better to design an inverter with slightly less power than the power of the PV generator. According to the guidelines of the inverter manufacturers, the power range of the inverters should be in the range of 0.8-1.2 PV generator power.

Task 3

Selection of PV modules and inverter

Inverter characteristics

The operating range of the inverter is between the voltage U_{start} and the voltage U_{max}. When the voltage on the DC side reaches the value U_{start}, the inverter turns on and starts searching for the maximum power point. If this point is between U_{min} and U_{start}, the inverter will turn on and start running. As long as the voltage does not exceed the minimum value of the MPPT (Maximum Power Point Tracking) range, it operates at partial power. The inverter is most efficient at U_{nom}, so the configuration of PV strings should be close to U_{nom} of the inverter.



Task 3

Selection of PV modules and inverter

The following slides will provide a step-by-step procedure for selecting the inverter and PV modules for a small PV installation.

An example file for a location in Bialystok (Poland): **PV - Tasks example Bialystok PV Task 3.xls**

Selection file for PV panels and inverter: **PV Task 3.xls**

Task 3

Selection of PV modules and inverter

ELECTRICAL CHARACTERISTICS AT STC						
Maximum Power (P_{max})	360W	365W	370W	375W	380W	385W
Open Circuit Voltage (V_{OC})	41.2V	41.4V	41.6V	41.8V	42.0V	42.2V
Short Circuit Current (I_{SC})	11.16A	11.23A	11.30A	11.37A	11.44A	11.51A
Voltage at Maximum Power (V_{mp})	34.2V	34.4V	34.6V	34.8V	35.0V	35.2V
Current at Maximum Power (I_{mp})	10.53A	10.62A	10.70A	10.78A	10.86A	10.94A
Module Efficiency (%)	19.73	20.01	20.28	20.55	20.83	21.10
Operating Temperature	-40°C to +85°C					
Maximum System Voltage	1000V DC/1500V DC					
Fire Resistance Rating	Type 1 (in accordance with UL1703)/Class C(IEC61730)					
Maximum Series Fuse Rating	20A					

STC: Irradiance 1000W/m², Cell temperature 25°C, AM1.5; Tolerance of Pmax: 0~+3%; Measurement Tolerance: ±3%

TEMPERATURE CHARACTERISTICS	
Nominal Operating Cell Temperature (NOCT)	43°C±2°C
Temperature Coefficients of P_{max}	-0.36%/°C
Temperature Coefficients of V_{OC}	-0.28%/°C
Temperature Coefficients of I_{SC}	0.05%/°C

PV module current at maximum temperature:

I_{sc}	=	11,3	A	PV module current in STC conditions,
Tr	=	85	°C	maximum operating temperature of the PV module,
α_T	=	0,05	%/°C	temperature coefficient for Isc.

$$I_{SC}(T_r) = I_{SC}\left[1 + (T_r - 25)\frac{\alpha_T}{100}\right]$$

PV module current at maximum temperature $I_{sc}(T_r)$:

$I_{sc}(T_r)$	=	11,30	x[	1	+(	85	-	25	)*	0,05	/	100	]=	11,64 A

Task 3

Selection of PV modules and inverter

ELECTRICAL CHARACTERISTICS AT STC						
Maximum Power (P_{max})	360W	365W	370W	375W	380W	385W
Open Circuit Voltage (V_{OC})	41.2V	41.4V	41.6V	41.8V	42.0V	42.2V
Short Circuit Current (I_{SC})	11.16A	11.23A	11.30A	11.37A	11.44A	11.51A
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STC: Irradiance 1000W/m², Cell temperature 25°C, AM1.5; Tolerance of Pmax: 0~+3%; Measurement Tolerance: ±3%

TEMPERATURE CHARACTERISTICS	
Nominal Operating Cell Temperature (NOCT)	43°C±2°C
Temperature Coefficients of P_{max}	-0.36%/°C
Temperature Coefficients of V_{OC}	-0.28%/°C
Temperature Coefficients of I_{SC}	0.05%/°C

Maximum PV module voltage at minimum temperature:

$$U_{OC}(T_r) = U_{OC}\left[1 + (T_r - 25)\frac{\beta_T}{100}\right]$$

β_T	=	-0,28	%/°C	PV module temperature coefficient,
Tr	=	-25	°C	minimum operating temperature of the PV module (in Poland),
U_{OC}	=	41,6	V	module voltage in open circuit.

Maximum voltage of the PV module:

$U_{oc}(T_r)$	=	41,6	x[	1	+(	-25	-	25	)*	-0,28	/	100	]=	47,42 A

Task 3

Selection of PV modules and inverter

Datasheet	SOFAR 1100TL-G3	SOFAR 1600TL-G3	SOFAR 2200TL-G3	SOFAR 2700TL-G3
Input (DC)				
Recommended Max. PV input power	1500Wp	2200Wp	3000Wp	3700Wp
Max. Input voltage	500V	500V	500V	550V
Start-up voltage	70V			
Rated input voltage	360V			
MPPT operating voltage range	50-500V	50-500V	50-500V	50-550V
Full power MPPT voltage range	110-450V	150-450V	200-450V	250-500V
Max. Input current MPPT	12A			
Maxnimun DC input short circuit current per MPPT	15A			
Number of MPPT/ String per MPPT	1/1			
Input terminal type	MC4/H4			

Allowable number of modules in a string connected in series:

U_{DCmax} = 550 V the maximum allowable voltage at the input to the inverter.

n_{max} = 550 / 47,42 = 11,598 = 11 sztuk

$$n_{max} \leq \frac{U_{DCmax}}{U_{OC(T_{min})}}$$

$$U_{OC}(T_{max}) = U_{OC}\left[1 + (T_{max} - 25)\frac{\beta_T}{100}\right]$$

Maximum voltage of the PV module $U_{oc}(T_{max})$:

$U_{oc}(T_{rmax})$ = 41,6 x[1 +(85 - 25)* -0,28 / 100]= 34,61 V

Task 3

Selection of PV modules and inverter

Datasheet	SOFAR 1100TL-G3	SOFAR 1600TL-G3	SOFAR 2200TL-G3	SOFAR 2700TL-G3
Input (DC)				
Recommended Max. PV input power	1500Wp	2200Wp	3000Wp	3700Wp
Max. Input voltage	500V	500V	500V	550V
Start-up voltage	70V			
Rated input voltage	360V			
MPPT operating voltage range	50-500V	50-500V	50-500V	50-550V
Full power MPPT voltage range	110-450V	150-450V	200-450V	250-500V
Max. Input current MPPT	12A			
Maxnimun DC input short circuit current per MPPT	15A			
Number of MPPT/ String per MPPT	1/1			
Input terminal type	MC4/H4			

Calculation of the minimum number of modules due to the permissible starting voltage of the inverter:

$U_{DCstart}$	=	70	V	inverter start-up voltage					
n_{min}	≤	70	/	34,61	=	2,02	=	3	sztuk

$$n_{min} \le \frac{U_{DCstart}}{U_{OC(T_{max})}}$$

Task 3

Selection of PV modules and inverter

ELECTRICAL CHARACTERISTICS AT STC						
Maximum Power (P_{max})	360W	365W	370W	375W	380W	385W
Open Circuit Voltage (V_{OC})	41.2V	41.4V	41.6V	41.8V	42.0V	42.2V
Short Circuit Current (I_{SC})	11.16A	11.23A	11.30A	11.37A	11.44A	11.51A
Voltage at Maximum Power (V_{mp})	34.2V	34.4V	34.6V	34.8V	35.0V	35.2V
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Operating Temperature	-40°C to +85°C					
Maximum System Voltage	1000V DC/1500V DC					
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Maximum Series Fuse Rating	20A					

STC: Irradiance 1000W/m², Cell temperature 25°C, AM1.5; Tolerance of Pmax: 0~+3%; Measurement Tolerance: ±3%

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Recommended Max. PV input power	1500Wp	2200Wp	3000Wp	3700Wp
Max. Input voltage	500V	500V	500V	550V
Start-up voltage	70V			
Rated input voltage	360V			
MPPT operating voltage range	50-500V	50-500V	50-500V	50-550V
Full power MPPT voltage range	110-450V	150-450V	200-450V	250-500V
Max. Input current MPPT	12A			
Maxnimun DC input short circuit current per MPPT	15A			
Number of MPPT/ String per MPPT	1/1			
Input terminal type	MC4/H4			

Determination of the permissible number of modules in a string due to the MPPT of the inverter (n_{min})

β_T	=	-0,31	%/°C	PV module temperature coefficient,
U_{DCmin}	=	250	V	minimum MPPT voltage of the inverter,
$U_{MPP(STC)}$	=	34,6	V	PV module MPPT voltage.

$$U_{MPP}(T_{max}) = U_{MPP(STC)}\left[1+\frac{\beta_T(T_{max}-25)}{100}\right]$$

Determination of the minimum voltage $U_{MPP}(T_{max})$:

$U_{MPP(Tmax)}$ = 34,6 *(1 +(-0,31 *(85 - 25)/ 100)= 28,16 V

$$n_{min} \geq \frac{U_{DCmin}}{U_{MPP(T_{max})}}$$

Minimum number of modules:

n_{min} >= 250 / 28,16 = 8,8765 PV modules, that is 9 PV modules

Task 3

Selection of PV modules and inverter

ELECTRICAL CHARACTERISTICS AT STC						
Maximum Power (P_{max})	360W	365W	370W	375W	380W	385W
Open Circuit Voltage (V_{OC})	41.2V	41.4V	41.6V	41.8V	42.0V	42.2V
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Datasheet	SOFAR 1100TL-G3	SOFAR 1600TL-G3	SOFAR 2200TL-G3	SOFAR 2700TL-G3
Input (DC)				
Recommended Max. PV input power	1500Wp	2200Wp	3000Wp	3700Wp
Max. Input voltage	500V	500V	500V	550V
Start-up voltage	70V			
Rated input voltage	360V			
MPPT operating voltage range	50-500V	50-500V	50-500V	50-550V
Full power MPPT voltage range	110-450V	150-450V	200-450V	250-500V
Max. Input current MPPT	12A			
Maxnimun DC input short circuit current per MPPT	15A			
Number of MPPT/ String per MPPT	1/1			
Input terminal type	MC4/H4			

Checking the maximum number of PV modules due to the power of the PV generator and the permissible power reaching the inverter:

P_{INV}	=	3700	W	allowable input power to the inverter,
P_m	=	370	W	power of a single PV module,
$P_{GEN}=P_m*n_{max}$	=	4070	W	PV generator power.
P_{GEN}/P_{INV}	=	1,1	PRAWDA	
Condition: P_{GEN}/P_{INV}	=	0,8	-	1,2
$P_{INV}*1.2/P_m$	=	12		
Selected:	12	PV modules and not less than:		9 PV modules

$$\frac{P_{GEN}}{P_{INV}} = (0.8 - 1.2)$$

EN

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