Parameters of photovoltaic panels

PREFACE

Photovoltaic panels are devices that intercept incoming sun radiation and convert it into a electricity with the use of photovoltaic effect. When semiconductors materials (the most widely used is silicon) are exposed to light, the some of the photons of light ray are absorbed by the semiconductor crystal which causes significant number of free electrons in the crystal. This is the basic reason of producing electricity due to photovoltaic effect.

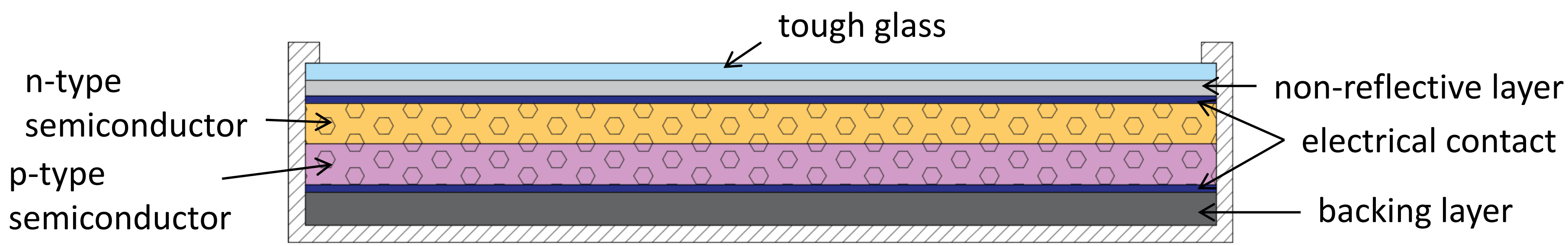


Fig. 1. PV panel construction (Source: personal collection)

PHOTOVOLTAIC PANEL PERFORMANCE

Performance of photovoltaic panel is described by two parameters: voltage and current output. The electrical power output from the panel is the product of this two variables. This three main operating parameters vary with the intensity of the solar irradiance and the temperature of the cell.

$$P = I \cdot V \; [W] \qquad (1)$$

The most common operating characteristic of photovoltaic panels are a current-voltage curve I-V and a power-voltage curve P-V. The I-V and P-V curves present operating parameters of device being under particular conditions of sunlight and temperature. The output performance of PV device is generally measured under standard test conditions (STC), ensuring a relatively independent comparison and output evaluation of different solar PV modules:

- a sollar irradiance 1000 W/m^2,
- an air mass AM1,5 (air in typical day with an average humidity and pollution),
- a panel temperature 25°C.

I-V CURVE

The I-V curve shows the possible combinations of current and voltage output of photovoltaic device.

The PV device produces its maximum current when there is no resistance in the circuit, for example when module is shorted. Then the voltage in the circuit is zero. This maximum current is called the short circuit current (I_{sc}).

The maximum voltage occurs when there is a break in the circuit and is called the open circuit voltage (V_{oc}). Under this condition the resistance is infinitely high and there is no current, because the circuit is incomplete.

There is a point on the knee of the curve where the maximum power output is located. The current for maximum power is described as I_{mp} and voltage as V_{mp}.

The I-V curve has a smooth shape with three distinct voltage regions:

1. A slightly sloped region above 0 V,
2. A steeply sloped region below V_{oc},
3. A bend in the curve in the region of the maximum power point.

I-V CURVE

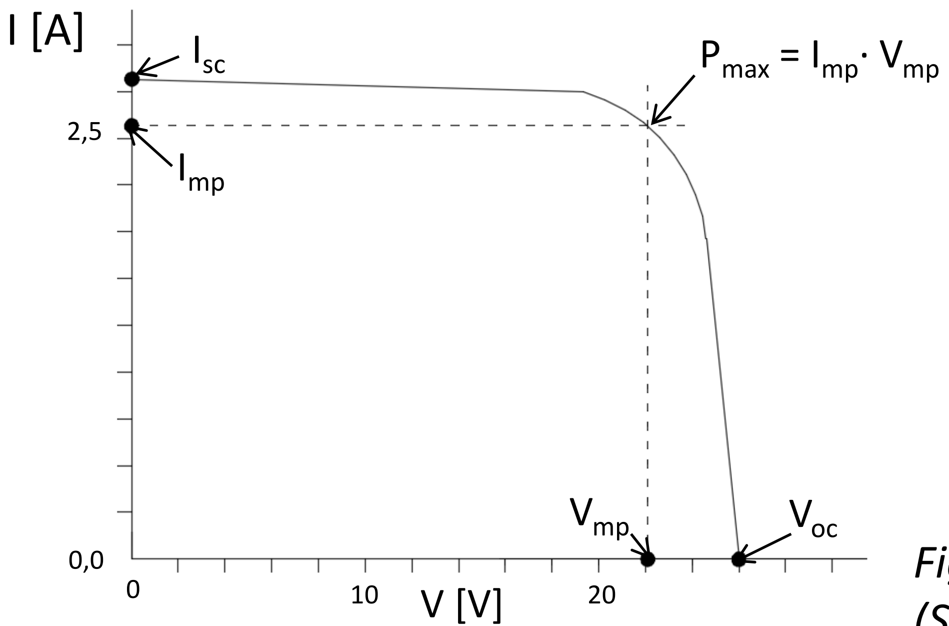


Fig. 2. I-V curve for PV panel (Source: personal collection)

The fill factor FF is the ratio of the maximum power to the product I_{sc} and V_{oc}. It determines the shape of I-V curve and describes the quality of PV panel. Typical commercial solar cells have FF > 0,70.

$$FF = \frac{I_{mp} \cdot V_{mp}}{I_{sc} \cdot V_{oc}} \qquad (2)$$

I-V CURVE FOR VARIABLE SOLAR IRRADIANCE AND CELL TEMPERATURE

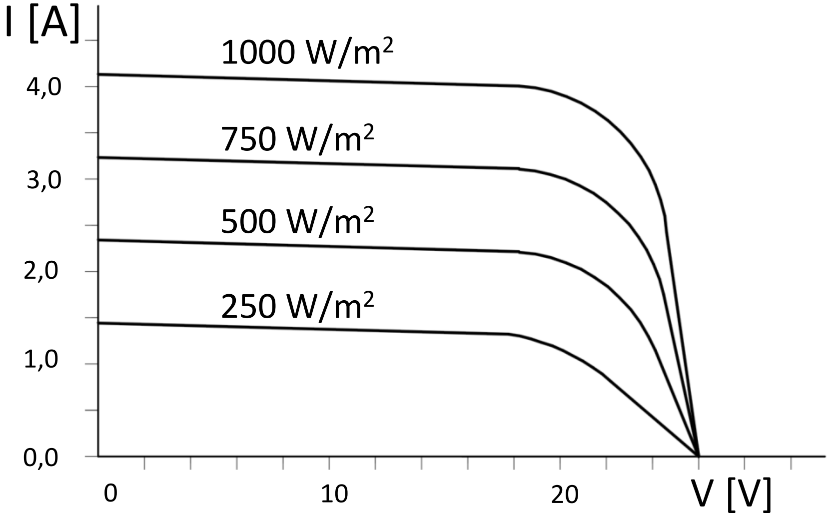


Fig. 3. I-V curve for variable solar irradiance and constant cell temperaturę (Source: personal collection)

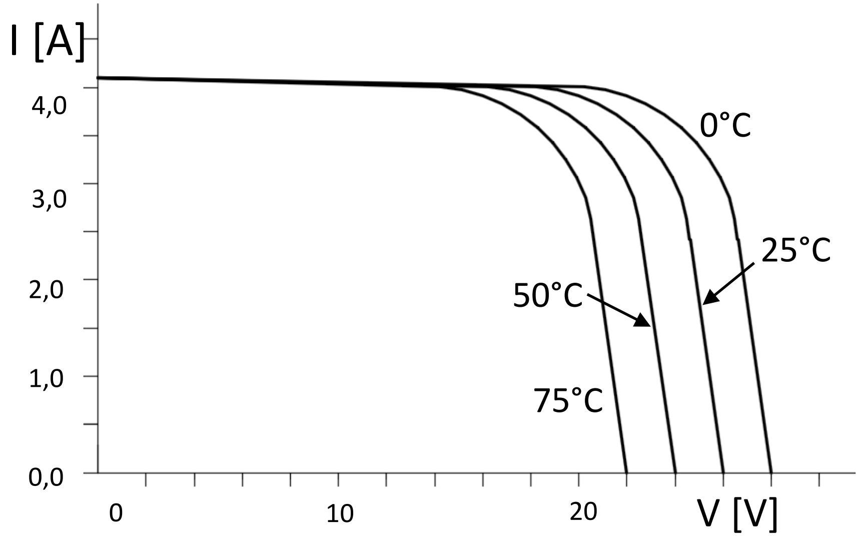


Fig. 4. I-V curve for variable cell temperature and constant solar irradiance (Source: personal collection)

P-V CURVE

P-V curve shows the relation between generated electric power and voltage output of photovoltaic device.

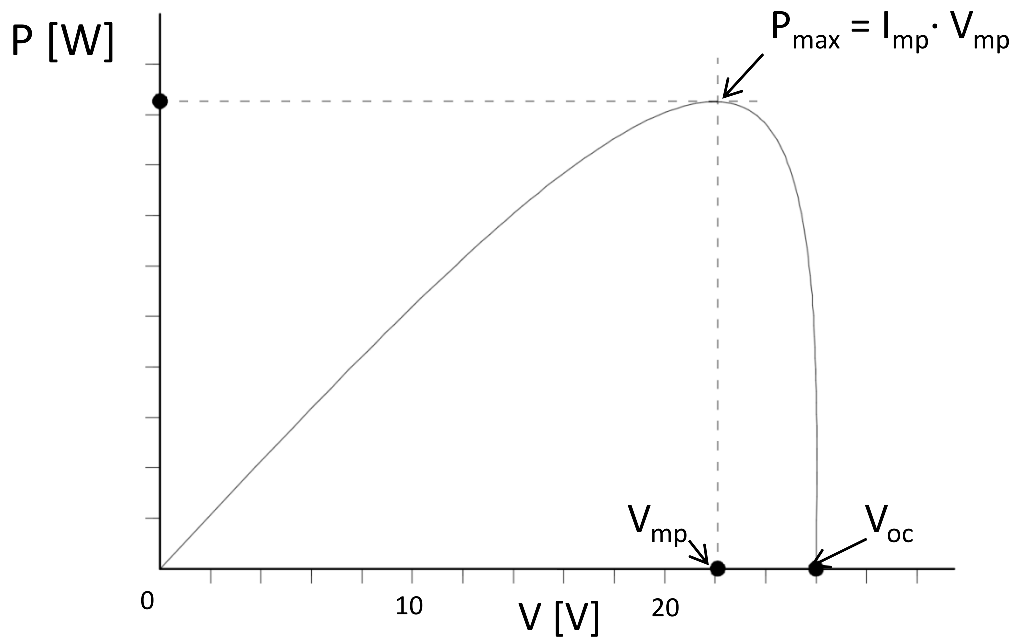


Fig. 5. P-V curve for PV panel
(Source: personal collection)

PANELS CONNECTED IN SERIES

When photovoltaic panels are connected in series the total voltage of each panel is summed together, but the electrical current stay the same.

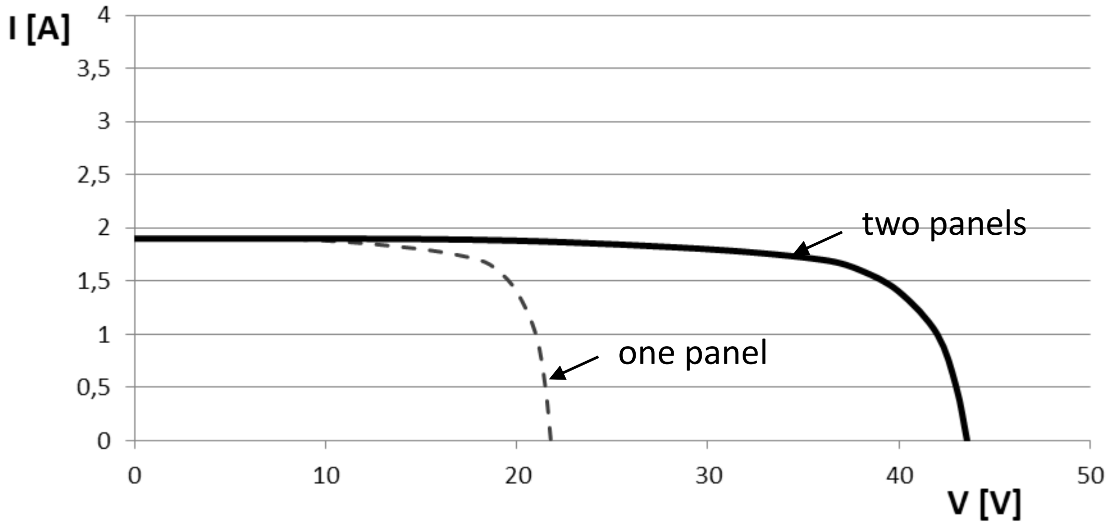


Fig. 6. I-V curve for two panels PV 66 W connected in series (E=0,5 kW/m^2) (Source: personal collection)

PANELS CONNECTED IN PARALLEL

When two PV panels are connected in parallel the electrical current for each solar panel are summed together, but the system voltage stays the same.

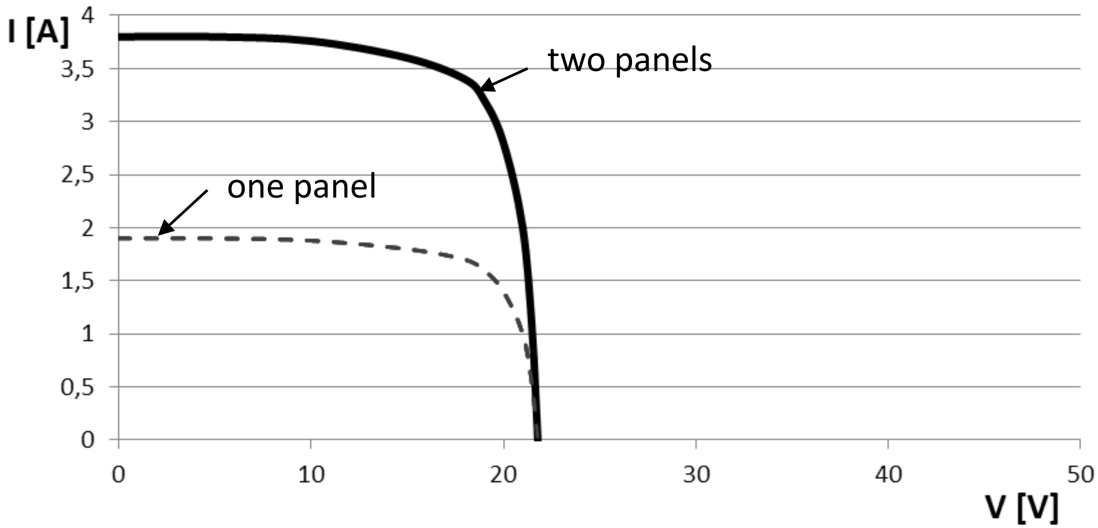


Fig. 7. I-V curve for two panels PV 66 W connected in parallel (E=0,5 kW/m²)
(Source: personal collection)

EFFICIENCY OF PHOTOVOLTAIC PANEL

The efficiency of a photovoltaic (PV) cell describes the percentage of the solar energy reaching the PV device that is converted into usable electricity.

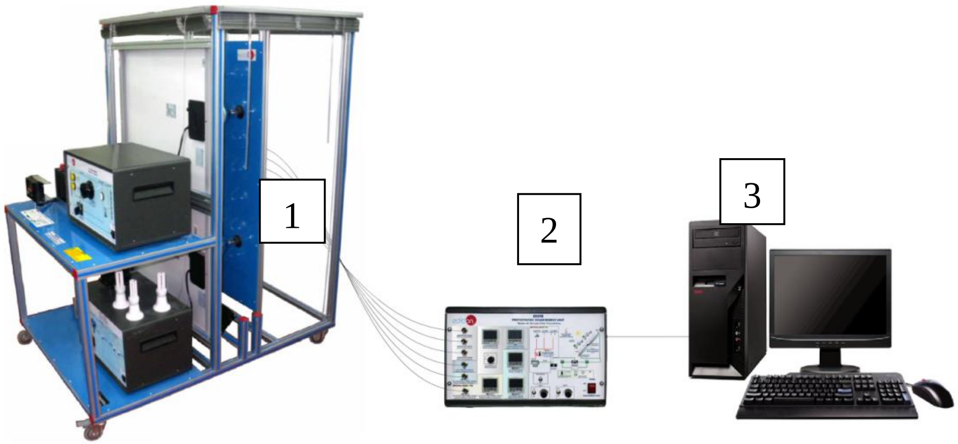
$$\eta = \frac{P}{A \cdot E} \qquad (3)$$

where:
P – rate of (useful) power output [W],
A – area of the panel [m^2],
E – solar irradiance falling on panel [W/m^2].

PV panel efficiency strongly depends on its construction:

- monocrystalline silicon - 14-17,5% (in lab approx. 24%),
- polycrystalline silicon - 11-15% (in lab approx. 18),
- amorphous silicon – 5-10% (in lab approx. 13).

SCHEME OF LABORATORY STATION



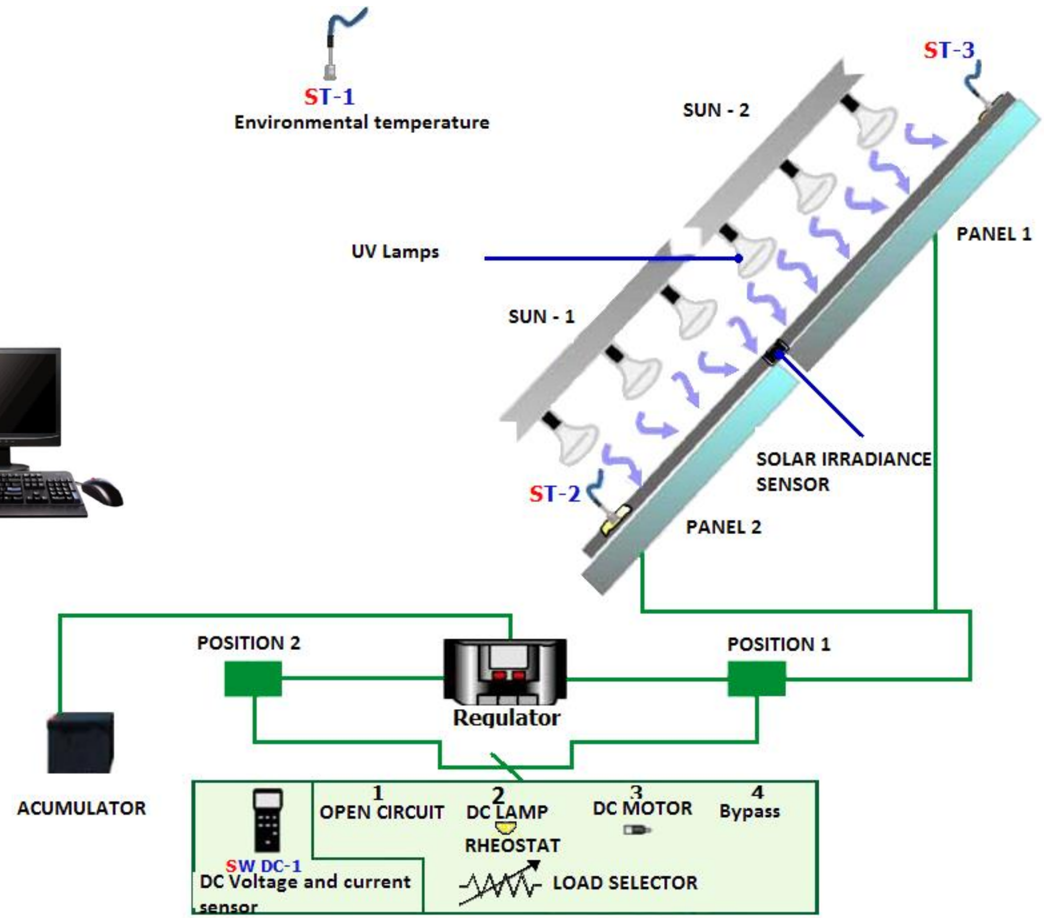


Fig. 8. Scheme of laboratory station:
1 – PV panel,
2 – control unit,
3 – PC

(Source: Edibon materials)

INSTRUCTION MANUAL

Part 1. Relation between solar irradiance and power generated by photovoltaic panels (optional)

1. Place the DC-load selector in position 2.
2. Disconnect the DC-lamps, which are connected in parallel with the rheostat (switch position - off).
3. Open the interface EESFC in PC.
4. Turn AFTER/BEFORE switch in BEFORE position.
5. Connect panels in PARALLEL.
6. Change the position of the load rheostat to 50% of R.
7. Switch on the PANEL-1.
8. Set the maximal value of SUN-2.
9. Write down the measured values of current I, voltage V and solar irradiance E.
10. Decrease the lamp irradiance by putting down SUN-2 to lower position.
11. Write down the measured values of current I, voltage V and solar irradiance E in printed table.

INSTRUCTION MANUAL
Part 1. Relation between solar irradiance and power generated by photovoltaic panels

Ressistance of reciving device			*R =*	*50%*
SUN-2	***PANEL-1***			
	I	***V***	***E***	***P***
	[A]	***[V]***	***[W/m²]***	***[W]***
				0
				0
				0
				0
				0
				0

12. Repeat 9 to 10 until SUN-2 reaches the minimal value.
13. Switch off the PANEL-1.
14. Fill in the table in MsExcel file to get the results.
15. Write the conclusions:
    A. Describe the relation between generated power and solar irradiance
    B. Describe the relation between generated voltage, current and solar irradiance

INSTRUCTION MANUAL

Part 2. Determination of I-V and P-V curves, fill factor FF, power and efficiency (optional)

1. Connect panels in PARALLEL.
2. Place the DC-load selector in position 2.
3. Set the maximal value of SUN-1 and SUN-2 and wait for stabilization of lamp irradiance (about 5-10 minutes).
4. Change the position of the load rheostat to 100% of R.
5. Switch on the PANEL-1.
6. Write down the measured values of current I, voltage V and solar irradiance E.
7. Repeat measurements for other positions of the load rheostat (from 90% to 0%).
8. Switch off the PANEL-1.
9. Place the DC-load selector in position 1 (NO LOAD).
10. Switch on the PANEL-1 and write down the value of open circuit voltage (V_{OC}).
11. Write down the ambient temperature and the panel temperature.

INSTRUCTION MANUAL

Part 2. Determination of I-V and P-V curves, fill factor FF, power and efficiency

12. Switch off the PANEL-1.
13. Fill in the table in MsExcel file to get the results.
14. Perform the following tasks:
a. Choose the maximum power generated during the exercise
b. Calculate the maximum nominal power generated by panels for Imp and Vmp values
c. Choose the maximum efficiency of photovoltaic panels received during the exercise

R	PANEL-1 (SUN-1 + SUN-2)				
	I	V	E	P	η
[%]	[A]	[V]	[W/m^2]	[W]	[%]
V_{oc} [V]				0,00	#DZIEL/0!
max				0,00	#DZIEL/0!
90				0,00	#DZIEL/0!
80				0,00	#DZIEL/0!
70				0,00	#DZIEL/0!
60				0,00	#DZIEL/0!
50				0,00	#DZIEL/0!
40				0,00	#DZIEL/0!
30				0,00	#DZIEL/0!
20				0,00	#DZIEL/0!
10				0,00	#DZIEL/0!
0				0,00	#DZIEL/0!
I_{sc} [A]	0,00	0,0	0,0	0,00	#DZIEL/0!
T_{panel} [°C]					
$T_{ambient}$ [°C]					

Instruction manual

Part 2. Determination of I-V and P-V curves, fill factor FF, power and efficiency

d. Calculate the maximum nominal efficiency of photovoltaic panels

e. Calculate fill factor FF for maximum power received during the exercise - use values Isc an Voc determined during the exercise

f. Calculate fill factor FF for maximum nominal power

15. Write the conclusions:
    A. Compare experimental I - V curve for Panel 1 and 2 with curve I-V , given by panels producer (especially shape, Isc and Voc values)
    B. Explain the source of differences between those I-V curves
    C. Compare the panel efficiency with the value given by producer
    D. Compare the fill factor with nominal value
    E. Explain all differences

INSTRUCTION MANUAL

Part 3. Panels connected in series/parallel (optional)

1. Connect panels in PARALLEL.
2. Place the DC-load selector in position 2.
3. Set the maximal value of SUN-1 and SUN-2 and wait for stabilization of lamp irradiance.
4. Change the position of the load rheostat to 100% of R.
5. Switch on the PANEL-1.
6. Write down in printed table the measured values of current I, voltage V and solar irradiance E.
7. Repeat measurements for other positions of the load rheostat (from 90% to 0%).
8. Switch off the PANEL-1.
9. Place the DC-load selector in position 1 (NO LOAD).
10. Switch on the PANEL-1 and write down the value of open circuit voltage (V_{OC}).
11. Write down in printed table the average panel temperature.
12. Switch off the PANEL-1.

INSTRUCTION MANUAL

Part 3. Panels connected in series/parallel (optional)

13. Connect panels in SERIES.
14. Place the DC-load selector in position 2.
15. Change the position of the load rheostat to 100% of R.
16. Switch on the PANEL-1 and PANEL-2.
17. Write down in printed table the measured values of current I, voltage V and solar irradiance E.
18. Repeat measurements for other positions of the load rheostat (from 90% to 0%).
19. Switch off the PANEL-1 and PANEL-2.
20. Place the DC-load selector in position 1 (NO LOAD).
21. Switch on the PANEL-1 and PANEL-2 and write down the value of open circuit voltage (V_{OC}).
22. Write down in printed table the average panel temperature.
23. Switch off the PANEL-1 and PANEL-2.
24. Connect panels in PARALLEL.
25. Repeat 14)-23) for parallel connection.
26. Switch off SUN-1 and SUN-2.
27. Fill in the table in MsExcel file to get the results.

INSTRUCTION MANUAL

Part 3. Panels connected in series/parallel

17. Write the conclusions:

  A. Describe differences between I-V curve for single panel and for panels connected in series/parallel (I_{sc} and V_{oc} values, maximum generated power)

  B. Describe what happens with generated current and voltage when panels are connected in series and in parallel

R	PANEL 1 (SUN-1 + SUN-2)				SERIES (SUN-1 + SUN-2)				PARALLEL (SUN-1 + SUN-2)			
	I	V	E	P	I	V	E	P	I	V	E	P
[%]	[A]	[V]	[W/m^2]	[W]	[A]	[V]	[W/m^2]	[W]	[A]	[V]	[W/m^2]	[W]
V_{oc} [V]				0,00				0,00				0,00
max				0,00				0,00				0,00
90				0,00				0,00				0,00
80				0,00				0,00				0,00
70				0,00				0,00				0,00
60				0,00				0,00				0,00
50				0,00				0,00				0,00
40				0,00				0,00				0,00
30				0,00				0,00				0,00
20				0,00				0,00				0,00
10				0,00				0,00				0,00
0				0,00				0,00				0,00
I_{sc} [A]	0,00	0,0	0,0	0,00	0,00	0,0	0,0	0,00	0,00	0,0	0,0	0,00
T [°C]												

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