Indoor testing of solar panels

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***Abstract*— This work represents an experimental study of different types of photovoltaic panels in laboratory conditions. The experiments have been performed with an experimental test bench for PV panels studies, realized in the Energy from Renewable Energy Sources (electrical aspects) Laboratory of the Technical University – Sofia. A number of experiments with different testing conditions have been conducted. The results show the possibilities of the laboratory equipment and mark a path for further studies.**

Keywords—component

I. Introduction

The correct testing of various photovoltaic panels requires repeatability of the results. This cannot be achieved by outdoor testing, because the testing conditions (solar irradiation, ambient temperature, angle at which the solar rays fall on the PV panel's surface etc.) cannot always be the same [1]. To properly test PV panels a laboratory setup with a so-called solar simulator is required [2], which permits to conduct various studies of PV panels in the same testing conditions [3]. This work presents the experimental test bench, realized in the Technical University of Sofia. Various tests of five different PV panels from five different technologies have been conducted and the results are presented below.

II. Experimental Test Bench

A. Solar Simulator

The solar simulator used in this study is represented at Fig. 1. It consists of an array of 32 projectors (four columns by eight rows), equipped with 230W, 230V halogen lightbulbs with luminous flux 4700 lm and colour temperature 3000 K. The power supply is AC with variable voltage, so that the light irradiation can be varied, to permit testing of the photovoltaic panels in different conditions. The AC voltage is varied manually by a potentiometer and a thyristor regulator. The solar simulator is also equipped with a fan, which permits the cooling of the tested photovoltaic panels.

B. PV analyzer

The IV curves of the tested PV panels are measured, using a PV analyzer shown at Fig. 2. The PV analyzer measures the PV panel's current form the open circuit (OC) current to the maximal possible current – the short circuit (SC) current. The analyzer also measures the solar irradiation in W/m^2 and the panel's temperature, and can represent the measured data for the OC voltage, SC current, current and voltage at the maximum power point etc. The PV analyzer's maximum power is 12 kW and its characteristics are shown at Table 1.

TABLE I. VA1011 PV ANALYSER'S CHARACTERISTICS

Parameter	***Range***	***Resolution***	***Accuracy***
DC voltage	1~1000V	0.01V/0.1V/1V	±1%±(1% of V_{oc}±0.1V)
DC current	0.1~12A	1mA/10mA	±1%±(1% of I_{sc}±9mA)
Solar irradiation	0~2000W/m2	1W/m2	±3%±20dgts
Temperature	20~85ºC	0.1ºC	±1%±1ºC

C. Tested Photovoltaic Panels

During this study five different PV panels form five different technologies have been tested – monocrystalline silicon (mSi), polycrystalline silicon (pSi), amorphous silicon (aSi), copper indium gallium selenide (CIGS) and cadmium telluride (CdTe). The panels and their rated parameters are represented in Table 2 [4].

Fig. 1. Photo of the realized experimental test bench.

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TABLE II. RATED DATA OF THE TESTED PV PANELS

Technology	*mSi*	*pSi*	*aSi*	*CIGS*	*CdTe*
Open circuit voltage Voc [V]	37.2	37.0	59.8	94.7	89.6
Short-circuit current [A]	8.79	8.61	3.45	1.65	1.23
MPP voltage Vmpp [V]	29.57	29.6	45.4	73.8	68.2
MPP current Impp [A]	8.2	8.12	2.82	1.49	1.1
Maximum power at STC [W]	240	240	128	110	75
Efficiency at STC [%]	14.8	14.8	9.01	11.70	10.42
Area of the PV panel [m^2]	1.62	1.62	1.42	0.94	0.72
Number of PV cells	60	60	90	149	116
Form fill factor FFc	0.74	0.75	0.62	0.70	0.68

The presented panels are tested with the realized experimental test bench. A block diagram of the setup is shown at Fig. 3.

III. EXPERIMENTAL RESULTS

The PV panels have been tested with the proposed solar simulator with AC power supply. During the tests some pulsations of the SC current of the PV panels has been observed – Fig. 4. This has led to the hypothesis that the pulsations of the SC current are due to the pulsations of the modified AC current, supplying the halogen lightbulbs which form pulsations in the light of these lightbulbs. To prevent this the lamps have been connected to 220 V DC grid. The PV panel's SC current obtained by using DC power supply for the solar simulator is shown at Fig. 5. It can be seen that the pulsations of the SC current are missing. This has led the team to compare the characteristics of the tested panels with AC and DC power supply of the solar simulator. To better compare the obtained IV curves of the tested panels a measurement of those curves under natural light conditions have also been done.

A. *Influence of the protection diodes on the IV curve*

Measurements of the IV curve of a mSi photovoltaic panel have been conducted in laboratory conditions with the presented solar simulator with AC power supply. The mSi panel is equipped with protection diodes, so that the shadowed cells can be excluded from the panel's circuit to prevent damage. The measured IV curves of the tested mSi PV panel are shown at Fig. 6. The same mSi panel has been tested with

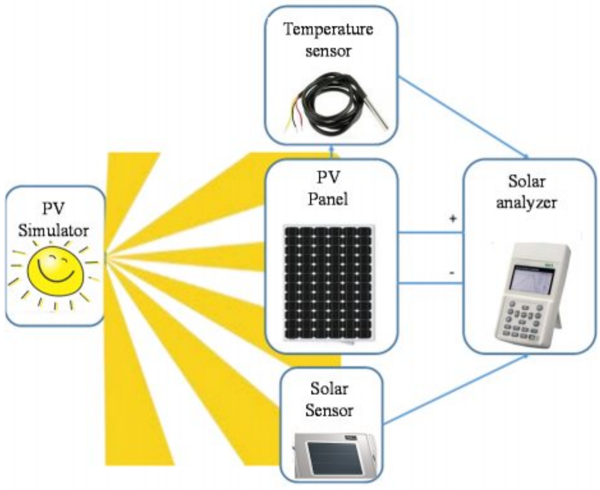

Fig. 3. Block scheme of the realized test bench

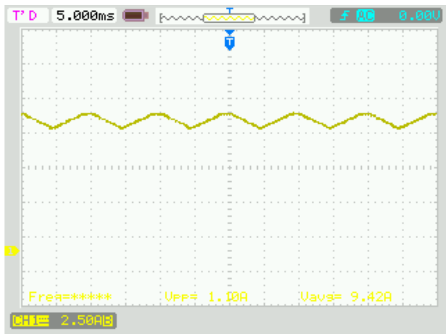
Fig. 4. Short-circuit current of the tested mSi PV panel with AC power supply of the solar simulator.

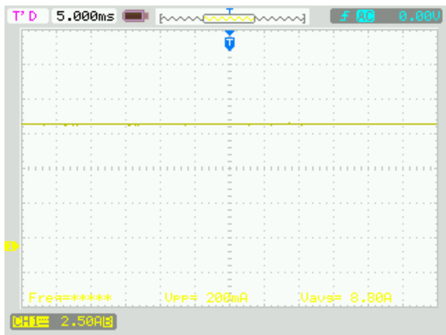
Fig. 5. Short-circuit current of the tested mSi PV panel with DC power supply of the solar simulator.


Fig. 2. Photo of the PV analyzer and its peripherals

DC power supply of the solar simulator at the same distances and the same conditions. It can be seen that the IV curves with the DC power supply lack the irregularities in the curve of the AC power supply due to the lack of pulsations from the lightbulbs. However, there are still some irregularities in the IV curve, due to the backwards diodes, protecting the PV panel's cells. This happens because the luminous flux of the light source is non-uniform and over the panel's surface there are areas where the light from the adjacent lightbulbs coincides, resulting in shadowlike effect. To remove the impact of the diodes on the IV curve the panel has been tested without those diodes and at different distances of the tested PV panel from the light source. However, removing the protection diodes results in worse IV characteristics in point of view of the SC current of the tested panel and can be harmful to the PV cells.

B. Comparison of the tested panels under different conditions

The five different PV technologies have been tested under similar conditions with AC and DC power supply of the solar simulator and with natural light. The IV curves of the panels under these conditions have been captured and they are represented at Fig. 7. From the results one can see that there is greater coincidence of the measured curves under different conditions of the mSi and pSi modules. The other technologies show great discrepancies between the results obtained with the solar simulator and under natural light from the Sun. The greatest nonconformity is obtained with the aSi panel, where the measured SC current of the panel under laboratory conditions is nearly three times lower than the rated SC current, which is obtained under natural light. This is due to the difference of the light spectrum emitted from the halogen lightbulbs and the sun. Fig. 8 represents the light spectrums of the sun [5] and the used halogen lightbulbs (obtained by a

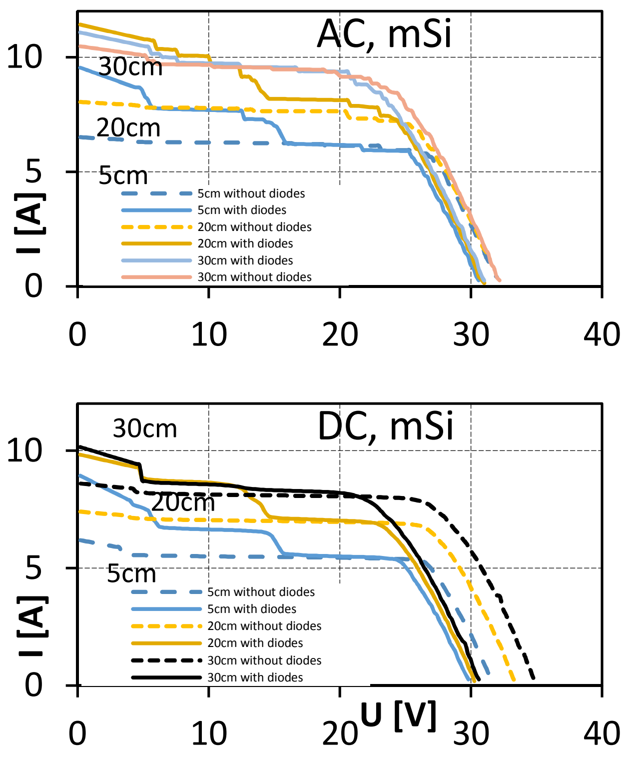

Fig. 6. IV curves of the tested mSi panel with and without protection diodes at different distances from the lightsource and different types of solar simulator's power supply.

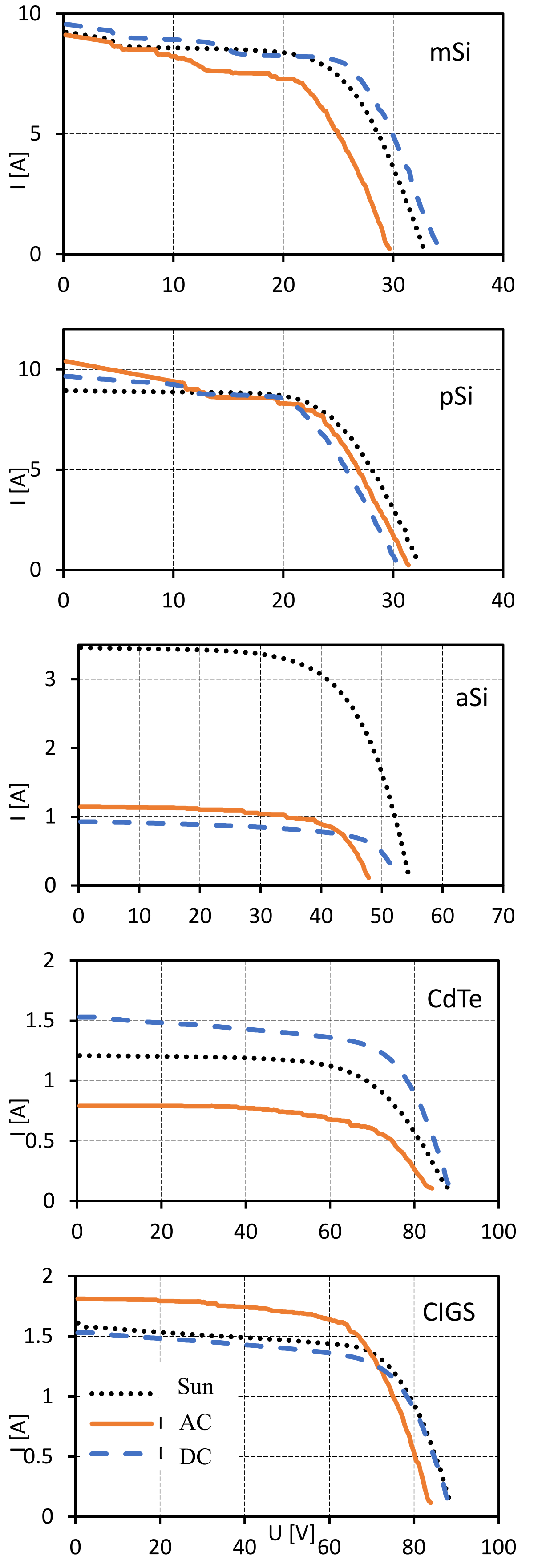

Fig. 7. IV curves of the tested PV panels under similar testing conditions with AC (orange line) and DC (blue dashed line) power supply of the solar simulator and under natural light (black dotted line).

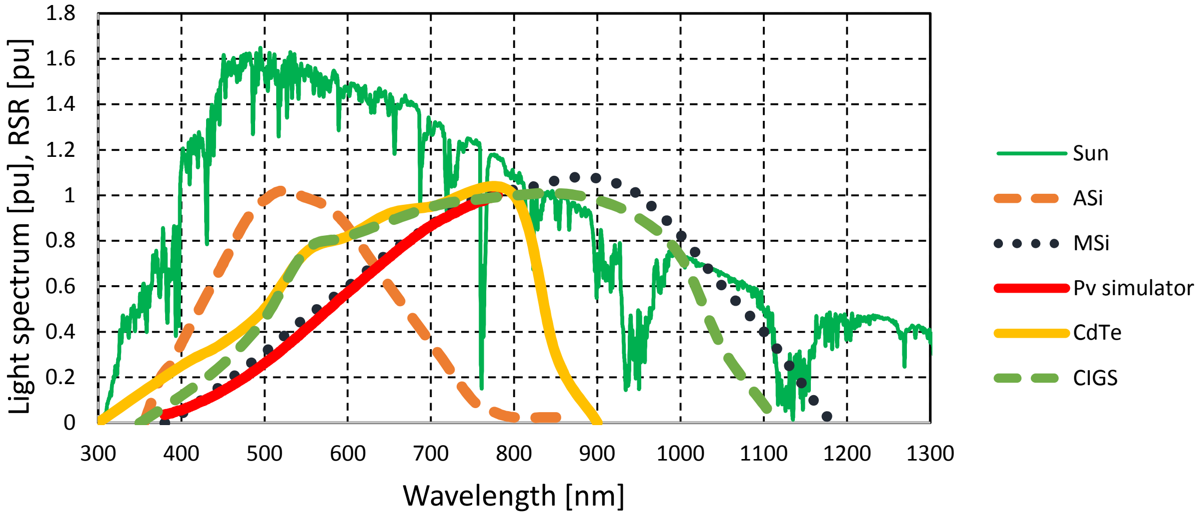

Fig. 8. Comparison of the light spectrums emitted by the Sun [5] and the solar simulator [6] and the spectral sensitivity of the tested PV panel technologies [7], [8].

method, presented in [6]), as well as the relative spectral response (RSR) of the tested solar panels [7], [8]. This shows, that this type of solar simulator can be used to compare panels from the same technology under same operating conditions, but cannot be used to compare PV panels from different technologies. The solar simulator with halogen lightbulbs however, can be reliably used to test PV panels from monocrystalline and polycrystalline silicon, due to the greater similarity of the measured IV curves with the simulator and under natural light.

IV. CONCLUSION

This work presents an experimental study of different types of photovoltaic panels in laboratory conditions. The experiments are made with an experimental test bench, realized in the Laboratory of Renewable Energy Sources (electrical aspects) in the department of "Electrical Machines" in the Technical University of Sofia.

Various experiments under different conditions have been conducted – irradiation, temperature, distance of the PV panel to the light source and different types of power supply of the halogen lightbulbs.

The light spectrum of the halogen lightbulb differs from the light spectrum of the Sun and has a different degree of coincidence with the PV panels' spectral sensitivity.

It has been established that the AC power supply of the halogen lightbulbs of the solar simulator leads to pulsations of the luminous flux. This leads to pulsations of the SC current of the panels and deformations of the IV curves. The solution of this issue is to use a DC power supply for the solar simulator.

The DC power supply of the solar simulator requires relatively high power controlled DC voltage source, so the light's intensity can be regulated.

Another issue is that when using halogen lamps to simulate the sun there is an unevenness of the luminous flux that falls onto the PV panels, which leads to a deformation of the measured IV curves.

A more homogenous luminous flux and a method for regulation of the DC power supply's voltage must be used for future improvements of the presented experimental test bench.

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