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دليل معمل

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فهرس المحتويات

معمل الطاقة الشمسية

الرساله

تتمثل رسالة معمل الطاقة الشمسية على تطوير مهارات الطلاب فى مجال الطاقة الشمسية وتطبيقاتها وكذلك يكون كمقر للباحثين فى مجال الطاقة الشمسية مجهز بكافة الامكانات التى تساعدهم فى ذلك

التجارب المعملية

- قياس واختبار الخلايا الشمسية
- قياس القدرة ورسم منحنى الخلايا الشمسية
- قياس الطاقة الشمسية فى منطقة مدينة المنصورة
- تجارب دوائر الكترونية بسيطة
- تجارب عمل محولات تيار مستمر بسيطة
- تجارب استخدام اجهزة قياس القدرة الشمسية.

الاتجاهات البحثية

- تطوير اجهزة تتبع أقصى قدرة شمسية.
- تطوير تكنلوجيا محلية لصناعة العواكس .
- ربط العواكس على التوازي .
- تطوير نظم الطاقة الشمسية المنعزلة عن الشبكة.
- تطوير نظم الطاقة الشمسية المرتبطة بالري.

1.Laboratory exercises of photovoltaic systems

This Book describes the experience in the implementation of modern systems of renewable energy sources and energy efficiency elements in the learning process through laboratory exercises. The lab contains equipment from the solar techniques based on the implementation of solar panels. Photovoltaic systems include the use of static photovoltaic panels, photovoltaic tracker and inverters for autonomous power supply of electricity consumers. Modern systems of inner and the outer light, elements of smart low voltage electrical installations systems for laboratory measurements and to determine the energy efficiency of residential buildings.

The paper presents exercises conducted in the Laboratory for renewable energy sources (LRES) with photovoltaic systems in the educational process of future professional engineers specialists at the photovoltaic lab.

1.1.PV Lab Procedures

Labs should be designed to reinforce classroom curriculum to include all job-related aspects of PV, both grid interactive and stand-alone, to include:

- Safety procedures and protocols
- Cell theory
- Electrical theory and applications
- Site evaluation: orientation, local climate, electrical service, structural considerations, shading, etc.

- System design: calculations, layout, component configuration, and integration.
- System Components: equipment identification, operation, and installation.
- Installation: processes and procedures for installing an adequate variety of mechanical systems and attachments.
- Trouble shooting and maintenance.

1.2.PV Lab Forms & Documentation

- Important Lab Activity Questions
- Sample PV Hands-on Lab Activity Form
- PV Hands-on Lab Activity Form Template
- Lab Documentation Considerations

1.3.Examples of PV Lab Exercises

1. Shading Experiment
2. PV Module Current Voltage Measurements
3. Grid-connected PV Assembly and Checkout
4. Effect of Tilt and Azimuth Orientation on PV Production
5. PV Power Output and IV Curves
6. Micro Inverter Rooftop Layout and Installation Writing Exercise part 1
7. Module Diagnostics/Testing

1.4.Test 1. Laboratory for renewable energy sources

Photovoltaic systems include the implementation of static PV panels, tracker and inverters for the power supply of autonomous consumers. Besides, there are modern systems for external and internal lighting and a wind generator with accompanying inverter and autonomous consumer group.

Fig 1. features of laboratory for the renewable energy sources

The exercises are conducted as a joint demonstration or by groups of three students in the presence of the course lecturer, teaching assistant and laboratory assistant.

1.5.Test 2. Efficient lighting

From the aspect of energy efficiency and electricity saving, special attention is paid to modern lighting sources for internal and external lighting and basic elements of "smart" electrical installations. Students get acquainted with the characteristics of energy-saving light sources, and the following experiments are performed:

- Measuring voltage, electricity and power, lux of conventional light sources for internal lighting (incandescent lamps), as well as modern light sources (energy-saving bulbs, LED lamps); statistical comparison of results is conducted and appropriate conclusions are made.
- Electrical measurements on the system of light sources for external lighting, measurement of the harmonic light source in cold and warm conditions. The comparison of the results of measurements on standard bulbs for public lighting (sodium, mercury) in relation to the results obtained with LED lamps for public lighting.

1.6.Test 3. Photovoltaic modules

A problem of the mismatch loss due to differences between single modules in the PV array is analyzed in [22]. Results show that the maximum power, the maximum power voltage and open circuit voltage are preferably represented by Burr probability density function and normal distribution function. Prediction of I-V characteristics for a PV panel by combining single diode model and explicit analytical model is presented in [23]. Fig. 3 shows demo models of PV cells used for basic laboratory reviews and the spotlight for achieving different levels of brightness in laboratory conditions. In Fig. 4 the equivalent scheme of the PV cell is shown. (Fig. 2).

Apart form the relatively high cost, the low PV module conversion efficiency is another factor that restricts the wide usage of PV systems [24]. Therefore, a power converter embedded with the capability of maximum power point tracking (MPPT) integrated with the PV system is essential for the application of this technology. Ref. [25], and [26] provide the comprehensive review of the available MPPT techniques, both in the uniform insolation and partial shaded conditions. Increasing the efficiency of the PV panel with the use of phase change material (PCM) is elaborated in [27].

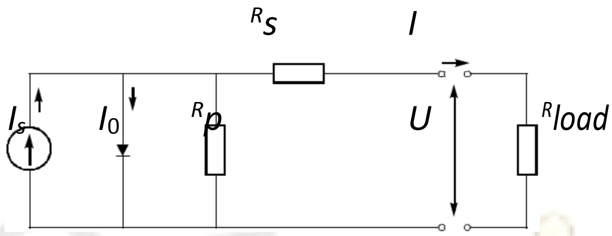


Fig 2. Equivalent scheme of PV cells.

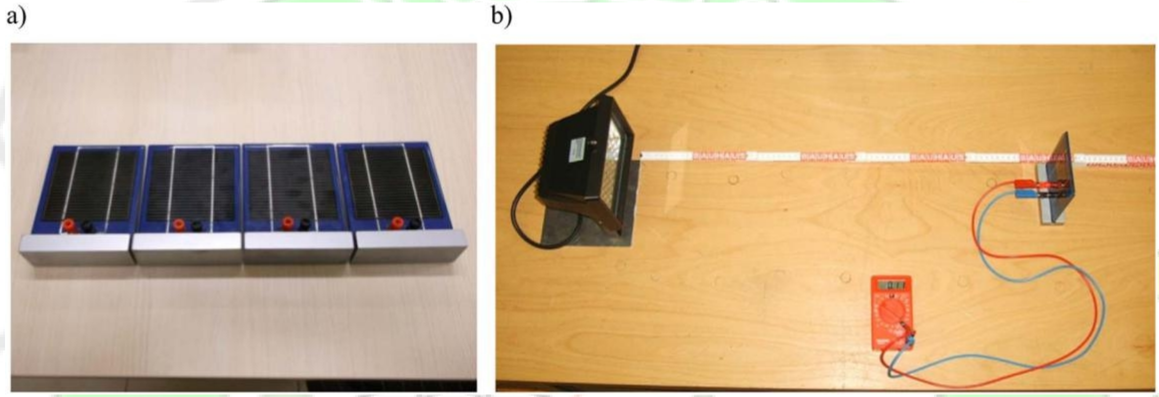


Fig 3. demo models of PV cells

Fig 4. Schematic diagram of the open circuit experiment.

Fig 5. Schematic diagram of the short circuit experiment.

1.7Basic exercises

Introduction to the operation of PV systems is divided into two parts. The main part represents the introduction to PV basic features, while the other part refers to the introduction into the realistic PV systems with DC/AC inverters and autonomous load.

Within the framework of the fundamental measurements on PV cells in the laboratory conditions, the students get acquainted with the characteristics and the way of work of the cells and modules in the trials carried out through five laboratory exercises:

1. Determination of open circuit voltage and short circuit current of photovoltaic cell depending on the volume of light;
2. Measuring of open circuit voltage and short circuit current of photovoltaic cell depending on the intrusion angle of the light rays;
3. Measuring of open circuit voltage and short circuit current of serial, parallel and combined link of solar cells;
4. Determination of the point of maximum power of solar cells ("MPP-Maximum Power Point", experiment of the adjustments per power) for different values of the lux at the surface of the photovoltaic cell; and
5. Experiment of shading a solar cell.

In the following text, the equipment, methodology of work, measurement results and conclusions made on the basis of the described experiments with PV cells are described in detail.

1.8.Laboratory equipment

Laboratory equipment contains the following elements:

- Four PV cells 0.5 V /1.0/0.5 W with 4 mm bushings [28],
- Two measuring devices (universal measuring instrument with a rechargeable 9 V - battery),
- One lux meter with a rechargeable 9 V,
- Battery charger for charging 9 V - batteries,
- Set of resistors on the aluminum holder (7 resistors /1 diode),
- Halogen source of radiation 200 W (with a spare halogen bulb),
- Conductors for measuring:
  a. 2 x red conductor of 100 cm length,
  b. 2 x blue conductor of 100 cm length,
  c. 3 x red conductor of 50 cm length,
  d. 3 x blue conductor of 50 cm length,
- Measuring pole, and
- Hood to cover the PV cells.

1.9Determination of PV characteristics of open circuit and short circuit

The aim of the exercise is to introduce basic modes of operation of solar cells, while the task of the exercise is as follows:

1. Study the way of performing the laboratory exercise;
2. Connect the equipment according to the schematic diagrams in Figs. 4 and 5;
3. Measure the open circuit voltage U_0 and short circuit current I_{SC} for different brightness values on the surface of the solar cell; and

4. Draw the diagrams $U_0 = f(E)$, and $I_{SC} = f(E)$ based on the measurements results.

The course of the exercises is as follows:

1. Pay attention during the measurement to the uniformity of the brightness of modules;
2. Measure the voltage and current separately, first in the open circuit and then in the short circuit for the same amount of brightness;
3. The measuring range for the voltage is 20 V/ DC, and for the circuit 10 A/DC;

Enter the measured values in the table and draw the corresponding graph of voltage and current

In Fig. 6 a and b the layout characteristics obtained from the open circuit and short circuit experiments performed on one photovoltaic cell are presented. Table 1 presents the results of measurements of voltage in the open circuit U_0 and short-circuit current I_{sc} of the photovoltaic cells.

When performing experiments, students can make the following observations:

- For low intensities of brightness the voltage of a cell reaches the maximum value, and
- The current increases linearly with the increase of light intensity. Students should notice this linear relationship and, if necessary, perform interpolation of the measuring points.

1.10.Determination of the open circuit voltage and short circuit current of PV cell depending on the angle of the light beam

The power of solar cells depends not only on the intensity but also on the incident angle of solar radiation. If more vertical light beams fall on the solar module, losses due to reflection will be less. The mobility of the PV module is technically feasible but requires certain costs. Therefore, it is important how the solar modules will be installed on the roof. The best is that the panels are placed exactly on the South side and at an angle corresponding to the precise setting place.

The aim of this exercise is to introduce the functional dependence of voltage and current of PV cells on the angle of incident radiation α, and the task of the exercise is to

1. Study the way of performing the laboratory exercise;
2. Connect the equipment according to the schematic diagrams in Fig. 7;
3. Measure the open circuit voltage U_0 and short circuit current I_{sc} of the cells for different values of the angle of light emission; and
4. Draw the diagram $U_0 = f(\alpha)$ based on the results of measurements.

The course of the exercises is as follows:

1. Place the sample solar cell on the intended surface with the indicated angles of rotation α;
2. Illuminate the solar module with 6000 lx, which corresponds to the distance of the radiation source from solar cells L =42 cm;
3. Measure the open circuit voltage and short circuit current for the corresponding angle of incident angle of light rays simulating a rotating panel; Enter the measurement results in the table and repeat the process until the angle is 90°;

4. The measuring range for the voltage is 20 V/ DC, and 10 A/DC for the circuit;
5. Draw the diagrams $U_0 = f(\alpha)$, $I_{SC} = f(\alpha)$ based on the results of measurements.

In Table 2 the measurement values of the open circuit voltage and short circuit current of photovoltaic cells, depending on the angle of incidence of radiation are given, and Fig. 8 shows the diagrams $U_0 = f(\alpha)$, $I_{SC} = f(\alpha)$

E	200	400	60	800	100	120	140
[Lux]	0	0	00	0	00	00	00
L	74.	54.					29.
[cm]	5	5	42	39	35	31.5	5
U_0	0.4	0.4		0.5			0.5
[V]	4	8	0.5	1	0.51	0.51	1
I_{sc}			45				
[mA]	150	310	0	580	720	880	990

Table 1. Results of measurements in the open circuit and short-circuit of photovoltaic cells.

a) b)

Voltage Current Isc

U_0 [V] [mA]

0.52 1200

1000

0.50

800

0.48

600

0.46

400

0.44

200

$U_0 = f(E)$ Isc = f(E)

0.42 0

200400600 8000 10000 12000 200 40600 8000 10000 12000

0 0 0 0 14000 16000 0 0 00 0 14000 16000

E [Lux]

E [Lux]

Fig6. Basic measurements on the photovoltaic cells: a) open circuit voltage U_0, b) short circuit current I_{sc}

α(°)	0	15	30	45	60	75	90
U_0 (V)	0.49	0.49	0.48	0.47	0.46	0.43	0.42
I_{SC} (mA)	460	450	410	350	260	140	40

Table 2. Open circuit voltage and short circuit current for the corresponding angle of incident angle of light rays.

When performing experiments, students can make the following observations:

- Open circuit voltage is in a wide range independent of the angle of incidence irradiation;
- Short circuit current changes by the cosine curve. However, when the angle of irradiation is 90°, zero current is not achieved because of the ambient light.

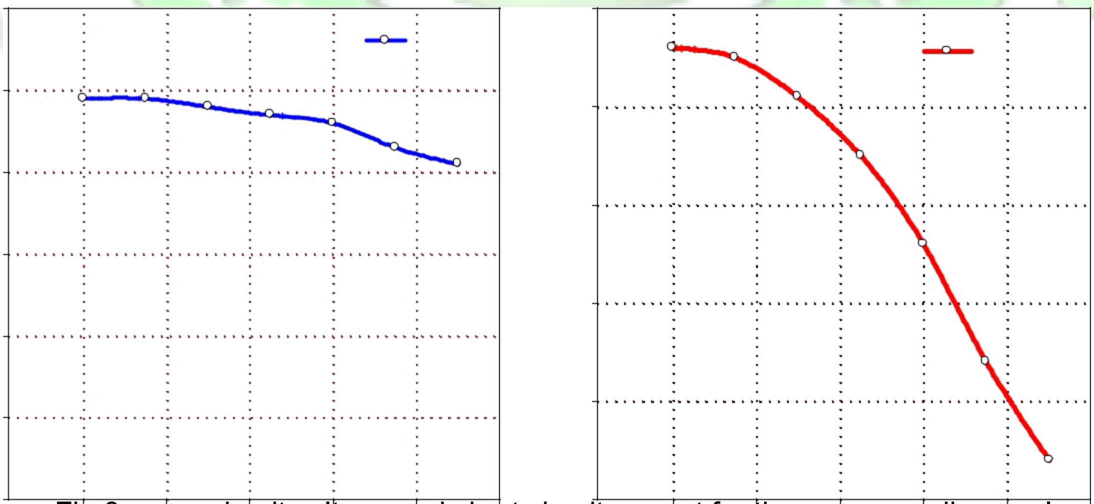


Fig 8. open circuit voltage and short circuit current for the corresponding angle

1.11.Testing of the series, parallel and combined link of PV cells

PV modules are connected in series to increase the voltage of the solar generator, and if necessary, to give a large current, the solar modules are connected in parallel. For devices that are connected to the network, the solar modules are often connected as mixed-serial and parallel, causing the inverter to bring higher voltages and higher currents and thus higher power.

The aim of the exercises is to show basic effects of serial, parallel and mixed connection of PV cells, and the task of the exercise is as follows:

1. Study the course of the laboratory exercises;
2. Connect the equipment according to the schematic diagrams in Fig. 9;
3. Measure the open circuit voltage and short-circuit current in series, parallel and mixed connection of solar cells; and
4. Make conclusion remarks based on the results of measurements.

The course of the exercises is as follows:

1. Perform the following measurement with illumination of 6000 lx, keeping the distance from the source of light and the solar cell about 42 cm; place solar cells in a semicircle, to make each cell be illuminated with the same intensity.
2. Measure the voltage and current one after another in accordance with the following electric schemes;

- Scheme 1: single solar cell;
- Scheme 2: two cells in series connection;
- Scheme 3: two cells in parallel connection;
- Scheme 4: two cells in series connection linked all together in parallel.

3. The measuring range for the voltage is 20 V/ DC, and 10 A/DC for the circuit.

The measured values of the open circuit voltage and short circuit current for series and parallel wiring of solar cells are shown in Table 3.

The worksheets contain the questions for discussion: What is achieved by the series link of solar cells? What is achieved by parallel connection of solar cells? What is achieved by the mixed connection of solar cells? Based on the results presented in the table students should conclude that the mixed connection results in twice the value of current and voltage, which actually represents a four-fold increase in power.

Some of the student observations are: Measurements were made using two universal measuring instruments, one set up to measure the current, and the other to measure the voltage, providing more accurate results. The measurement of the short circuit currents should be performed quickly in order to avoid overheating of the cells. When reconnecting the solar cells, it is needed to switch off the light source that is rapidly heated. With the increase of the cell temperature, the cell power decreases by 0.5% /°C.

	Scheme 1	Scheme 2	Scheme 3	Scheme 4
U_0 (V)	0.48	0.99	0.49	0.79
I_{SC} (A)	0.48	0.47	0.90	0.87

Table 3. Open circuit voltage and short circuit current of the series, parallel and mixed link of the PV cells.

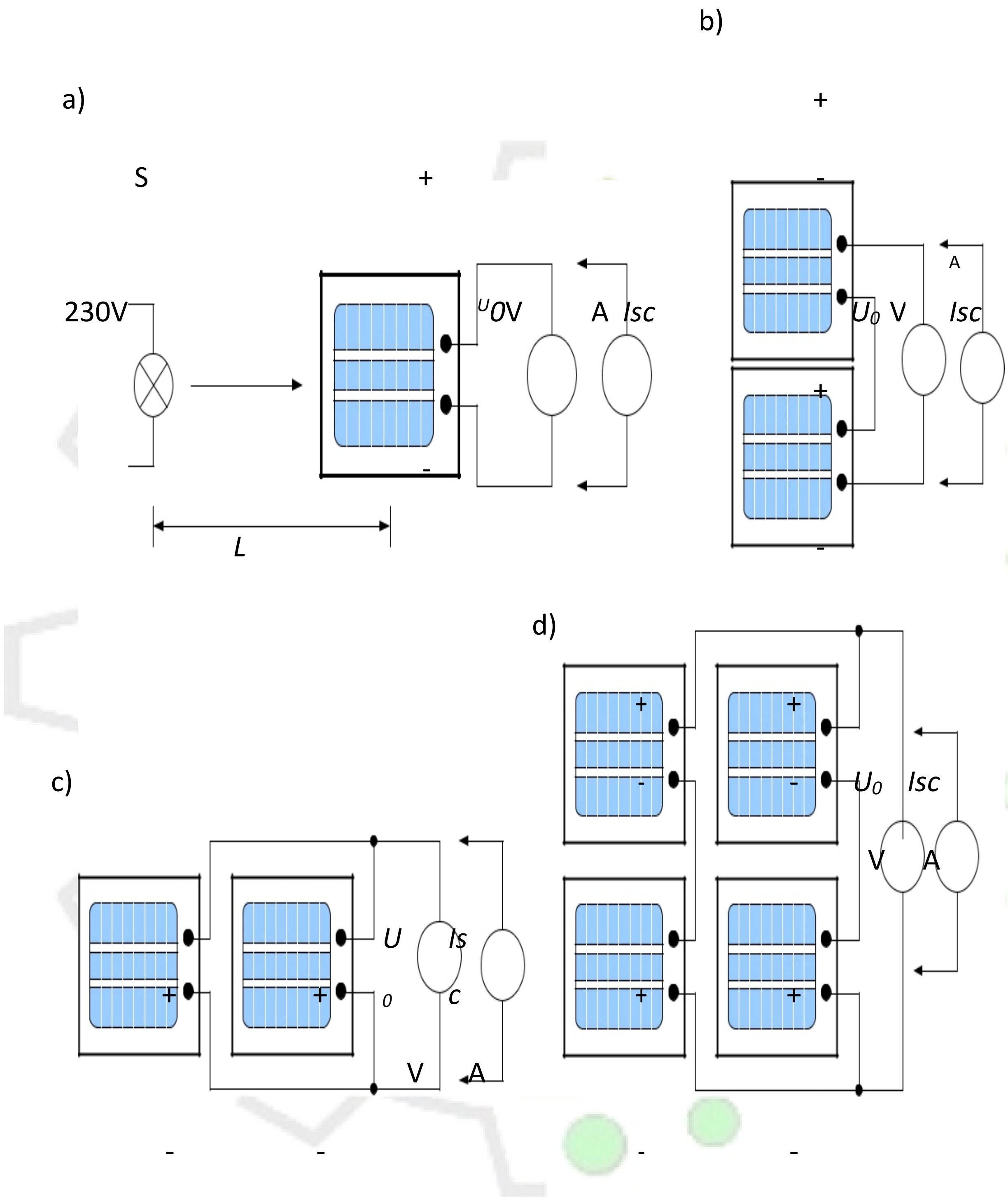


Fig.9. Schemes for testing of the series, parallel and combined connection of solar cells. a) single cell, b) series link, c) parallel link, d) mixed wiring.

1.12. Determination of the PV maximum power point

PV cell produces DC voltage that is converted in the inverter DC/AC to the alternating voltage. The point of maximum power (MPP) is a point at which the solar cell produces maximum power. To achieve the highest degree of efficiency of the cell, the inverter must at all times, depending on the load and illumination, work at the point of maximum power.

The MPP of a solar cell for different lighting can be simulated through the measurement of current and voltage for different resistors in the circuit, keeping the constant brightness. Individual measurement results are plotted through the previously calculated power (P= UI).

The aim of the exercise is the experimental verification of the principle of adjustments by power of the PV cell.

The task of the exercise is as follows:

1. Study the course of the laboratory exercise;
2. Connect the equipment to the schematic diagrams in Fig. 10;
3. Measure the voltage and current of solar cells for different values of resistors that are available (R1 to R7); and
4. Draw a diagram on the basis of the measured power as a function of the voltage of the PV cells P= f(U) and determine the MPP.

The course of the exercises is as follows:

- Lighten the PV cell with 6000 lx; Distance of the light source L =42 cm;
- Measure the intensity of the light source and adjust the cell bright-ness;
- Connect resistors R1 to R7 successively one after another into the PV cell circuit;

- Measure the current and voltage one after another; The measuring range for the voltage is 20 V /DC and current 10 A /DC;
- Calculate the power based on the measured values of voltage and current (P= U·I);

  Repeat the experiment with the brightness of 2000 lux, at the distance of the light source L =74 cm.

The measured voltage and current values in determining the operating point of maximum power at 6000 lux and 2000 lux are given in Tables 4 and 5, respectively. Fig. 11 shows the current and MPP of the photovoltaic cell.

Brightness 6000 lx							
Resistance	R_1=0 Ω	R_2 =	R_3 =	R_4 =	R_5 =	R_6 =5.6 Ω R_7 =	
		0.18Ω	0.39 Ω	0.82 Ω	2.7 Ω		15 Ω
U_1 (V)	0.04	0.12	0.2	0.32	0.43	0.45	0.47
I_1 (A)	0.47	0.46	0.44	0.36	0.15	0.08	0.03
P_1 (W)	0.019	0.055	0.088	0.115	0.065	0.036	0.014

Table 4. Determination of the MPP for 6000 lux.

Table 5 Determination of the MPP for 2000 lx.

Brightness 2000 lx							
Resistance	R_1=0 Ω	R_2 = 0.18 Ω	R_3 = 0.39 Ω	R_4 = 0.82 Ω	R_5 = 2.7 Ω	R_6 = 5.6 Ω	R_7=15 Ω
U_2 (V)	0.01	0.04	0.07	0.13	0.28	0.35	0.38
I_2(A)	0.16	0.15	0.15	0.15	0.1	0.06	0.02
P_2	0.00	0,0	0.01	0.0	0,0	0,0	0.007

Table 5. Determination of the MPP for 2000 lux.

The students can perform the following observations based on the measured values:

- A MPP exists for each intensity of brightness;
- The PV cell has a MPP for the appointed load; and
- To achieve the maximum power of the PV cell, the inverter has to adjust its working point to the current values of sunlight.

1.13.Shading of PV cells

The PV module is usually made of a serial/parallel connection of individual cells. In case one of the PV cells is in the shadow, it cannot generate current and voltage and acts as a consumer in relation to other cells. This results in an increase in the PV cell operating temperature since the electrical power of the shaded cell is converted into the heat. The consequence is the overheating of the shaded PV cell and destruction of its structure known as the hot-spot effect. The problem is solved by setting the appropriate anti-parallel “bypass” diodes. Due to significantly less resistance of the diodes in the conducting state, the current is redirected through the bypass diodes

The aim of the exercise is the experimental testing the effect of shading of PV cells. The task of the exercise is as follows:

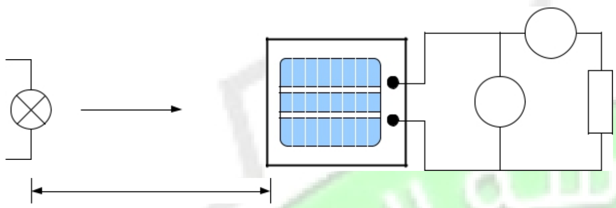
1. Study the course of the laboratory exercise;
2. Connect the equipment according to the schematic diagrams in the following figures
3. Measure the open circuit voltage and short circuit current of the PV cell system in three cases: all three cells are directly exposed to the light rays; one of the three PV cells is shaded; and one of the three PV cells is shaded and there is an adequate bypass diode;
4. Comment on the results and draw conclusions based on the results of measurements.

The course of the exercise is as follows:

- Connect the PV cell in the serial link;
- Lighten the PV cell with 6000 lx; Distance of the light source is L =42 cm;
- Measure the intensity of the light source and adjust the cell bright-ness;

The measured voltage and current values in the case of normal operation, one PV cell shaded, and the shaded PV cell with bypass diode, at 6000 lx brightness are shown in Table 6.

a



b

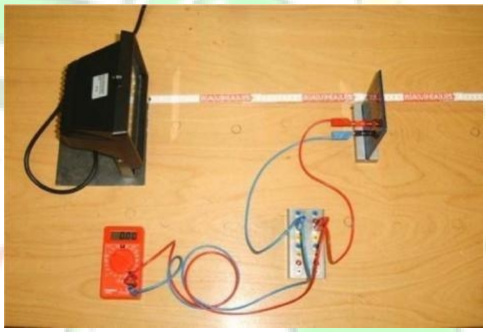


Fig. 10. Determination of maximum power point of solar cells: a) principle scheme, b) hardware.

a)

b)

Cur rent I_1[A], I_2 [A]

Power P_1[W], P_2 [W]

0.5

0.14

$I_2 = f(U)$

$P_1 = f(U)$

$I = f(U)$

1

0.12

$P_2 = f(U)$

0.4

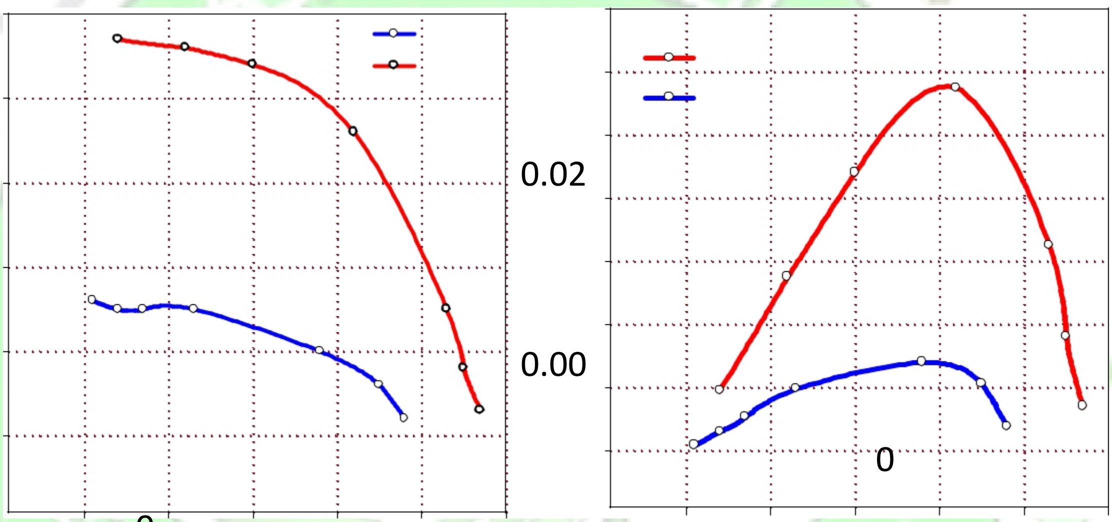
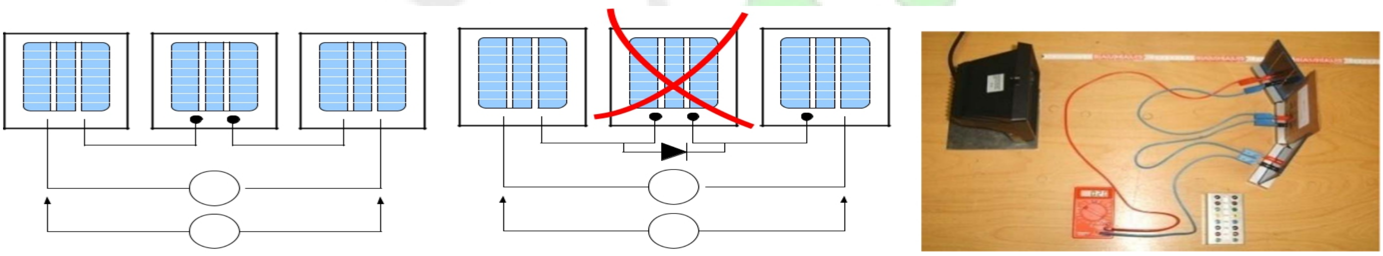


Fig. 11. Diagram of the measured current and power for the experiment of MPP determining: a) $I_1=f(U)$, $I_2=f(U)$; b) $P_1= f(U)$, $P_2= f(U)$.



a **b** **c**

Fig. 12. Schemes for performing the experiment of shading of the PV cell: a) regular system, b) system with shaded PV cell, c) hardware

1.14.Conclusion remarks about DC exercises

The values measured by laboratory assistants may differ from the measured values of students, because:

- Specified intensity of PV cell illumination cannot be accurately set,
- Measured values of voltage and currents depend on the PV cell temperature; by brightening PV cells by halogen source of light, the cell is heated; and finally
- PV cells and measuring equipment have a certain tolerance.

However, deviations of the measured values have not a significant impact on the conclusions reflected.

a) b)

Fig. 13. School PV system: a) with a single ax tracking sun position. b) static PV panels.

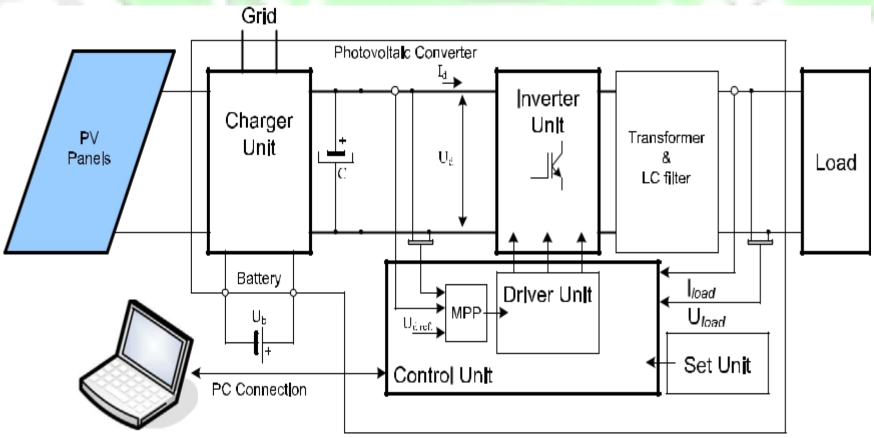


Fig. 14. Block diagram of the school PV system with inverter and own loading.

Fig. 15. Test unit of inverter system in the school laboratory.

1.14.1 Shading Experiment

Introduction and Background

Shading can provide a major obstacle to the performance of photovoltaic systems. Before spending time and money on a PV system that may not meet customer expectations, it is important to verify that there is adequate solar access. Many people attempt to 'eyeball' the site and guess as to whether the site will have shading or not. This can be incredibly inaccurate, and often leads to unexpected shading.

There are many relatively accurate methods for determining shading. The most common method is to use a piece of equipment called a Solar Pathfinder. Any device used for this purpose must take into account the sun's path throughout the year and the latitude range.

Objectives

• Recognize potential solar radiation obstructions

• Use the Solar Pathfinder properly to obtain shading information

• Interpret the results of the Solar Pathfinder

• Understand the implications of shading

Equipment

• Solar Pathfinder

• Wax marking pencil

• Compass (Note: Users need to know the difference between solar South and magnetic South.)

Procedure

The Solar Pathfinder can be used any time where reflections can be seen in the plastic dome. It is not necessary to have a clear day – in fact, it is actually beneficial to have a cloudy day since it reduces the glare when viewing he reflections.

1. Check the Solar Pathfinder data sheet (the black form with lines) to make sure it is for the correct latitude.2. Place the Solar Pathfinder on a corner of the mock roof in the plane of the array.

3. Place the Solar Pathfinder facing solar South, with the December lines closest to the South. The Solar Pathfinder compass is relatively inaccurate, so having a second, more accurate one is helpful. In either case, you should also have a rough idea of the magnetic declination, or number of degrees difference between solar South and magnetic South. Adjust the direction to align it with solar South.

4. Level the Solar Pathfinder so the bubble is directly in the center of the black circle on the bubble leveler.

5. From directly overhead, look for reflections in the plastic dome. In particular, look for trees, buildings, telephone/power poles, and other stationary objects.

6. Using the wax pencil, draw a line that traces the outline of these potential obstructions.

7. Examine the resultant form. Determine if there will be any shading between 9am and 3pm any time during the year.

8. Mark the roof and/or a to-scale drawing to indicate whether that particular spot is acceptable for PV.

9. Repeat everywhere on the roof where the array may be placed – especially the corners, the center, and along the edges of the potential PV array footprint.

Results/ Review Questions

1. Where on the roof could you place the array?

2. What were the obstructions?

3. When would these limit your system output?4. Approximately what percentage of power would your array lose as a result of shading?

5. What would cause this shading pattern to change over time? How realistic is it that this profile will change?

6. Given the same exact site at 45 ºN latitude, would the shading be greater or less?

1.15.Photovoltaic system with the inverter

The second group of the trial is performed on the off -grid PV system set in the schoolyard and connected to the appropriate inverter DC/AC of 2000 VA with the autonomous group of consumers.

Through this group of experiments the students learn the basic PV system installation, connection and commissioning of PV systems of low power. By using an appropriate software application for monitor-ing system parameters the students learn the possibilities of setting the inverter mode.

The PV system with a single ax tracking the sun position is shown in Fig. 13a, and b shows the static PV panels in the schoolyard. The block diagram of the school PV system with inverter and loading is presented in Fig. 14, the test unit of the inverter system in the laboratory is in Figs. 15, and 16 shows the layout application interface for inverter monitoring.

1.15.1. Real PV system exercises

The following experiments are performed on the test unit:

1. Continuous monitoring of electricity production from the PV system, and data recording on hourly, daily, weekly and monthly bases;
2. Setting the appropriate PV system mode through the control panel using the technical guidance;
3. Measurement of power quality parameters on several consumer groups using the professional measurement unit METREL®; and
4. Comparative analysis of the behavior of the static PV panels in relation to the PV system with tracking of the sun position.

The input voltage of the PV system is shown in Fig. 17a, while the AC active power is presented in Fig. 17b. Battery voltage and output inverter voltage are given in Fig. 18 a and b, respectively.

1.15.2. Safety and health at work

Having in mind that the experiments on the PV system test station are carried out at mains voltage 230 V, regardless of the fact that the PV system is not connected to the distribution grid, it is necessary to strictly take care of occupational safety and health measures for teachers, laboratory technicians and students in accordance to the regulations [29,30]. Accordingly, the following protection measures are applied in the Laboratory for renewable energy:

- Protection against direct and indirect contact voltage applying TN-C-S protective grounding system;
- Electrical (galvanic) separation;
- Protection against short-circuit and overloading by using the automatic fuse; and
- Protection against direct voltage by using the insulated housing.

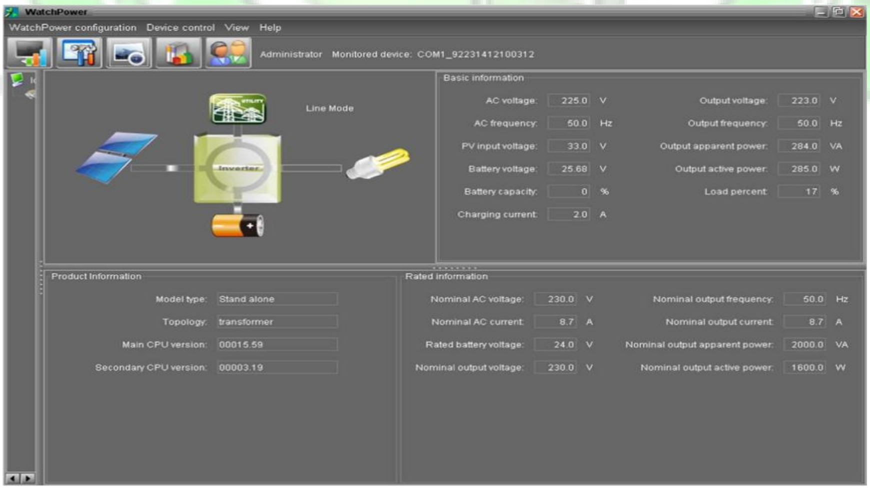


Fig. 16. Application interface for inverter monitoring.

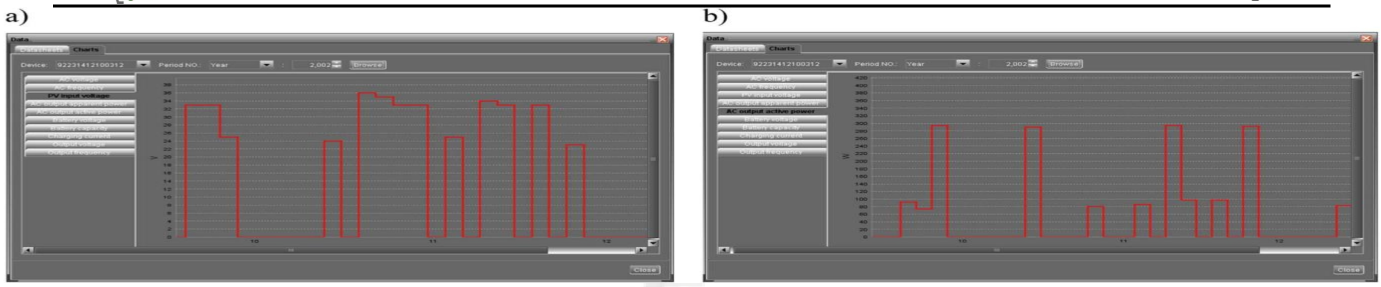


Fig. 17. Parameters monitoring: a) PV input voltage U_{PV} (V), b) AC output active power P_{AC} (W).

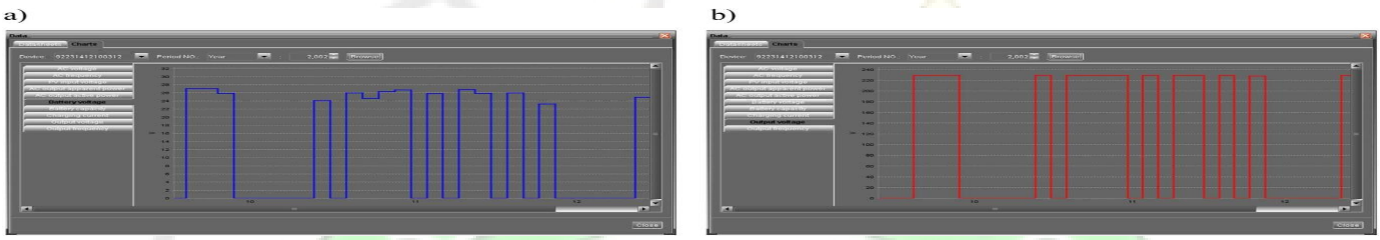


Fig. 18. Parameters monitoring: a) Baterry voltage U_b(V), b) Output inverter voltage U_i (V).

1.16.Conclusions

Designing of the curriculum and syllabus in the field of renewable energy sources is a challenge for teachers of professional higher education schools and universities. This particularly refers to professional higher education schools, since from the professional engineer it is expected to have both solid theoretical knowledge and practical skills applicable in the industry.Despite the significant potential for the application of renewable energy, as well as the feed-in tariff , due to the unfavorable loans and complicated procedure for obtaining permission to connect DG to the grid, the number of implemented renewable energy sources in Serbia is negligible. As a result, Serbia lacks practical knowledge, good practice and experience in the construction and operation of renewable energy sources. It is clear that investing in human resources in the field of renewable energy sources is of great importance.The objective of this paper is to present the authors’ experience in implementation of the laboratory exercises on the PV systems, performed in the teaching process at the specialist studies at the HTSPSN, Serbia. Special attention was paid to the comprehensiveness of content with the aim to familiarize future engineers with basic principles and technologies of modern photovoltaic systems. By careful selection of experiments and demonstration exercises in the laboratory the authors tended to cover all relevant activities in the field of photovoltaic technology. By applying the proposed laboratory exercises students can check all the theoretical principles taught within the subject Small power plants and renewable energy sources. Furthermore, they can notice and comment on the differences of measured and expected results. The authors strongly believe that by performing proposed laboratory exercises the overall process of electrical engineering education, consisting of teaching theoretical units, practicing numerical calculations and performing computer simulations, is significantly improved.The general impression is that the students showed a high motivation to work in the Laboratory for Renewable Energy Sources and were well prepared for carrying out practical experiments. The discussions and comments of the students stated in their reports indicate they understand the principles of work and have adopted the practical knowledge of modern photovoltaic systems. Therefore, it is not surprising the average grade regarding laboratory exercises is 8.72 out of 10, earned in the 2015/2016 academic year.It can be concluded that Laboratory for Renewable Energy Sources in the HETSPS in Novi Sad is of great importance for the educational process since besides laboratory exercises it is used for various student research activities and preparation of seminars and undergraduate thesis. Also, the experience shows positive student feedback as well as employers' satisfaction regarding the acquired knowledge and skills necessary for engineering tasks in the field of renewable energy sources.

References

[1] Masters GM. Renewable and Efficient Electric Power Systems. John Wiley and Sons

[2] Foster R, Ghassemi M, Cota A. Solar Energy: Renewable Energy and the Environment. Taylor and Francis Group; 2010.

[3] Stigka EK, Paravantis JA, Mihalakakou GK. Social acceptance of renewable energy sources: a review of contigent valuation applications. Renew Sustain Energy Rev 2014;32:100–6.

[4] Kandpal TC, Broman L. Renewable energy education: a global status review. Renew Sustain Energy Rev 2014;34:300–24.

[5] Energy Law, Official Gazette of the Republic of Serbia, No. 84/2004.

[6] Energy Strategy of the Republic of Serbia by 2025, The Ministry of Mining and Energy of the Republic of Serbia, ⟨http://www.parlament.gov.rs⟩.

[7] White Book of the Power Industry of Serbia, Belgrade, 2009.

[8] Technical recommendation no. 16: technical requirements for the connecting of small p ower plants to the grid 2003 Serbian Electric Power Industry Belgrade.

[9] Gvozdenac D, Ciric R, Tesic M. Prospects of Energy Efficiency Improvement and Development of the Renewable Energy Sources in Province of Vojvodina, 20thWorld Energy Congress, 12–, Rome; 2007.

[10] Gvozdenac D, Ciric R, Petrovic J. Energy efficiency and renewable energy sources in province of vojvodina–strategy implementation program. 6th MedPower 2008 2008, [paper No. 226, Thessalonica].

[11] Ciric RM, Stipanovic P. Connecting Solar Plants to Distribution Network-Experience from Serbia [ISSN: 1757–3971, V7. No.1]International Journal of Renewable Energy Technology. Inderscience Publishers, IJRET −73253; 2016. p. 69–82.

[12] Ciric RM, Rajakovic NLJ. Concept Modules and Objectives of the Syllabus Course: Small Power Plants and Renewable Energy Sources, International Journal of Electrical, Computer, Energetic, Electronic, Communication Engineering, International Science Index 113, World Academic Scientific Engineering and Technology Conference (WASET), EISSN: 2010–3778, Vol. 10, No.5, pp. 447–452; 2016.

[13] Pavlovic T. Physics and Technique of Solar Energy. Belgrade: Gradjevinska knjiga; 2010.

[14] Ma T, Yang H, Lu L. Solar photovoltaic system modeling and performance prediction. Renew Sustain Energy Rev 2014;36:304–15.

[15] Cotfas DT, Cotfas PA, Kaplanis S. Methods to determine the dc parameters of solar cells: a critical review. Renew Sustain Energy Rev 2013;28:588–96.

[16] Ciulla G, Brano VL, Dio VD, Cipriani G. A comparison of different one-diode models for the representation of I-V characteristic of a PV cell. RenewSustain Energy Rev 2014;32:684–96.

[17] Hasan MA, Parida SK. An overview of solar photovoltaic panel modeling on analytical and experimental viewpoint. Renew Sustain Energy Rev 2016;60:75–83.

[18] Rawat R, Kaushik SC, Lamba R. A review on modeling, design methodology and size optimization of photovoltaic based water pumping, standalone and grid connected system. Renew Sustain Energy Rev 2016;57:1506–19.

[19] Chin VJ, Salam Z, Ishaque K. An accurate modeling of the two-diode model of PV module using a hybrid solution based on differential evolution. EnergyConvers Manag 2016;124:42–50.

[20] Jordehi AR. Parameter estimation of solar photovoltaic (PV) cells: a review. Renew Sustain Energy Rev 2016;61:354–71.

[21] Kichou S, Silvestre S, Guglielminotti L, Mora-Lopez L, Munoz –Ceron E. Comparison of two PV array models for the simulation of PV systems using five different algorithms for the parameters identification. Renew Energy 2016;39:270–9.

[22] Gasparin FP, Buhler AJ, Rampinelli GA, Krenzinger A. Statistical analysis of I-V curve parameters from photovoltaic modules. Sol Energy 2016;131:30–8.

[23] Zhang Y, Gao S, Gu T. Prediction of I-V characteristics for a PV panel by combining single diode model and explicit analytical model. Sol Energy 2017;144:349–55.

[24] IEC 61724, Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis, 1998-04, ⟨https://webstore.iec.ch/preview/info_iec61724%7Bed1.0%7Den.pdf⟩.

[25] Kamarzaman NA, Tan CW. A comprehensive review of maximum power point tracking algorithms for photovoltaic systems. Renew Sustain Energy Rev 2014;37:585–98.

[26] Liu L, Meng X, Liu C. A review of maximum power point tracking methods of PV power system at uniform and partial shading. Renew Sustain Energy Rev 2015;53:1500–7.

[27] Stropnik R, Stritih U. Increasing the efficiency of PV panel with the use of PCM. Renew Energy 2016;97:671–9.

[28] Technical documentation and test equipment. Germany: Robert Bosch School, WBZU, Ulm; 2007.

[29] Law on Safety and Health at Work, Official Gazette of Republic of Serbia, No. 101/ 05.

[30] Regulations on general measures of protection on work from the hazardous effects of electricity in buildings intended for work, premises and work sites, Official Gazette of the Republic of Serbia, No. 21/89.