



# An Educational Kit to Promote Teaching of Photovoltaic Systems

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(First received 29 May 2020 and in final form 31 August 2020)

(DOI: 10.31590/ejosat.745109)

**ATIF/REFERENCE:** Erduman, A., Yuzer, E.O., Durusu, A. & Yildiz, F. (2020). An Educational Kit to Promote Teaching of Photovoltaic Systems. *European Journal of Science and Technology*, (19), 916-922.

## Abstract

In this study, an educational kit was presented for photovoltaic panel education and this simple and fast training set enables to show relation between soiling, tilt angle and the power output of photovoltaic panels. The designed training set is low cost and suitable for the use of high school and undergraduate students. The developed training set was used for educational purposes on the students of Hakkari University Colemerik Vocational School, Electrical Program. A questionnaire was conducted to determine the effect of photovoltaic system education on the learning status of students using the designed education set. The results obtained from the survey showed that the designed experiment set was suitable for photovoltaic system education and students because positive feedback was received from the majority of students.

**Keywords:** Photovoltaic module, Soiling, Educational kit

## Fotovoltaik Sistemlerin Öğretimini Destekleyen Bir Eğitim Kiti

### Öz

Bu çalışmada, fotovoltaik (PV) sistem eğitim seti sunulmuştur. Bu basit ve hızlı eğitim seti, fotovoltaik panellerin kirlenme, eğim açısı ve güç çıkışı arasındaki ilişkiyi göstermeyi sağlamaktadır. Tasarlanan eğitim seti düşük maliyetli olup lise ve lisans öğrencilerinin kullanımına uygundur. Geliştirilen eğitim seti Hakkari Üniversitesi Çölemerik Meslek Yüksekokulu Elektrik Programı öğrencilerine eğitim amaçlı kullanılmıştır. Tasarlanan eğitim setini kullanan öğrencilerin fotovoltaik sistemleri öğrenmedeki etkisini belirlemek için anket yapılmıştır. Anketten elde edilen sonuçlar, tasarlanan deney setinin fotovoltaik sistem eğitimine uygun olduğunu öğrencilerin çoğunluğundan alınan olumlu geri dönüş ile göstermiştir.

**Anahtar Kelimeler:** Fotovoltaik modül, Kirlenme, Eğitim kiti

## 1. Introduction

According to the agreement at the Climate Change Summit of the United Nations, it was accepted that the world temperature increase does not exceed 2 degrees centigrade until 2030 and to be limited to 1.5 degrees centigrade if possible [1]. In addition to the efficient use of energy sources, which are important in climate change, it is also important to choose correct source of the energy. According to International Energy Agency, an increase in the use of all fuels is observed. Especially, a rapid increase has been observed in the use of

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fossil based fuels over the years. Although the use of energy sources such as the sun and wind has increased, it is not common as fossil fuels [2].

Solar energy usage is supported by developed and developing countries for individual or power plant-based applications due to the increasing demand for energy [3], [4]. The most important reasons behind the increase in the installation of solar power plants are the decrease in the costs of the power plant components (panel, inverter, etc.) with the developing technology, the reduction of fossil resources, the more environmentally friendly, the faster the installation and the lower maintenance cost compared to other types of plants during operation [5]. Considering the individual users, solar energy based system can be integrated quickly into the existing structure and installed in a simple way without technical knowledge and experience compared to other sources. Efficiency of solar panels depend on two important parameters. These are structural and environmental parameters. Structural parameters was studied previously and detailed information was given about the methods and techniques used in production by Green et al. Environmental factors significantly affects the efficiency of solar power plants [6]. Environmental variables can be classified as temperature, humidity, amount of radiation, shading, cloudiness effect, rain, snow and pollution [4], [7]–[10]. In addition to above mentioned studies about environmental parameters, it was realized that PV panel efficiency values decrease especially due to soiling in dusty areas. Many different methods have been used to investigate the effects of pollution in literature [8]–[12].

In the analysis of electrical energy systems, analyzing the structural and environmental components and choosing the right systems make a great contribution in reducing production costs and increasing system reliability [13], [14]. To do this, many educational modules at different levels are used in educational institutions. For example, Torres et al. designed a mobile training kit that teaches the effects of photovoltaic systems on the network (electrical grid). This set explains to the students establishment of a simple solar energy system and principles of connection to the grid [15].

In the study of Ayedh et al., the working principles and maximum working states of solar energy system components were examined in the training module [16]. In different study, Bilu et al. developed and used a simulation program to evaluate investment cost of system. This program enables to simulate connection of PV systems to the network and calculate connection type investment costs [17]. Thus, it has been showed to determine the investment costs variables and their effects on the system at the feasibility stage.

In engineering education, many models have been tried in the last 20 years in order to increase the quality of education while reducing education costs. Effective models have been determined by innovations and change studies [18]. Especially with the start of the industry 4.0 period, new areas will appear in higher education. Therefore, the preparation of the necessary infrastructures for these areas and the training of students accordingly are important [14]. In order to prepare more qualified educational facilities, students need to learn and evaluate together by seeing, living and analyzing them at the same time [19]

As far as authors' knowledge, no educational material showing changes in output power due to soiling of PV panels was found in the literature. In order to refer insufficient solar energy education materials in literature, an educational kit and research module has been developed and it has been tested by students.

In this study, the mathematical and technical structure of the educational kit were introduced first, then the test setup and the operation of the system were explained. The educational setup was used by students in the practice of "Electric Energy Production, Transmission and Distribution" course, coded as ELK201, Hakkari University, Colemerik Vocational School, Electrical Program. A questionnaire was applied to determine the intelligibility of the soiling and tilt angle effects on PV panel output (solar energy generation) after student used educational kit. The questionnaire was prepared as a Likert scale and results of the questionnaire were evaluated in the results and discussions section.

## **2. Methodology**

The photovoltaic effect can be defined as the electrical potential that occurs between the two different materials when the common junction of these materials is illuminated by photon radiation. The working principle of a PV cell is similar to the classic p-n junction diode. When the light is absorbed by the junction, the absorbed photon energy is transferred to the electron structure of the material and causes the formation of charge carriers around the junction region. The output current voltage characteristic of a solar cell is similar to the diode as solar cell not exposed to radiation. The output current-voltage (Figure 1(a)) and voltage-power characteristic (Figure 1(b)) of a module are given in Figure 1, respectively [20]. Process flow of experimental measurement is shown in Figure 2. More detail about experimentation is explained in experimental setup section.

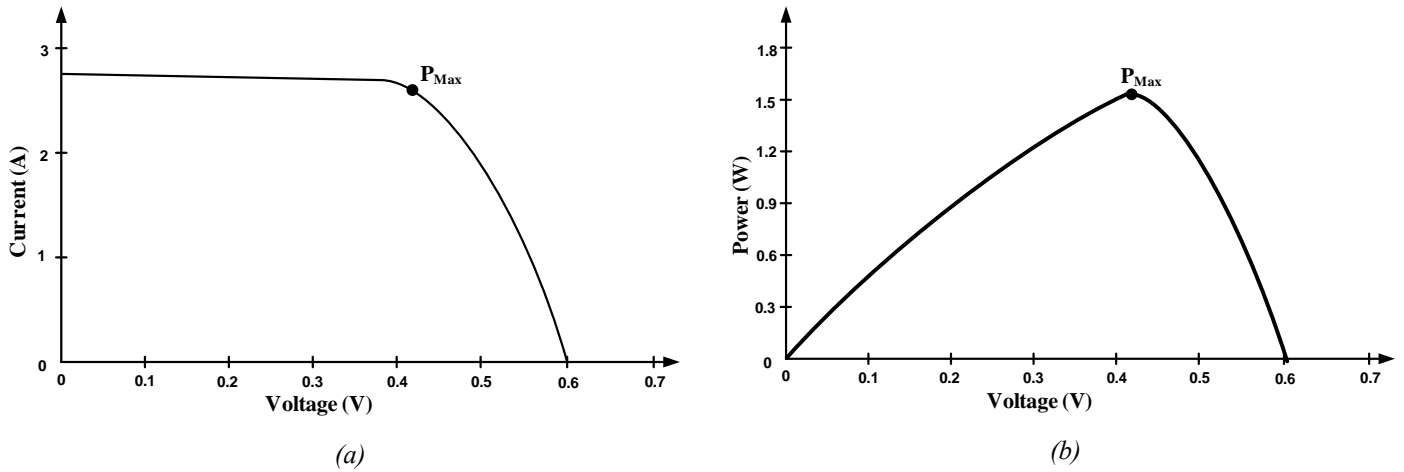


Figure 1. (a) PV current-voltage characteristic, (b) PV voltage-power characteristic

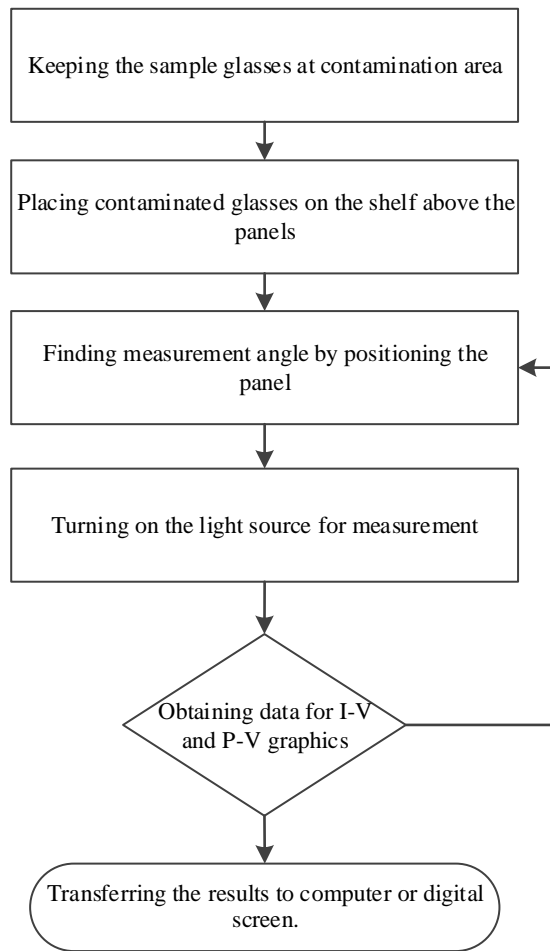


Figure 2. Process flow of experimental measurement

### 3. Experimental setup

The designed and fabricated system to measure pollution on solar panels is given in Figure 3.

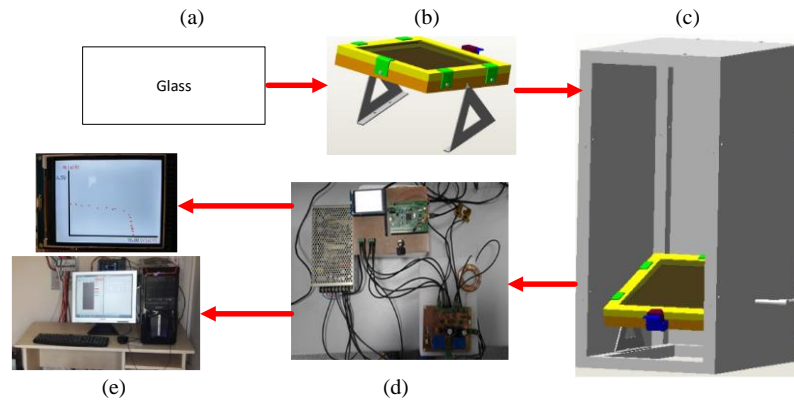


Figure 3. Experimental measurement system

In this design, glass pieces (Figure 3 (a)) were cut in same width of panel to measure the soiling on the panels. These glass parts were placed on surfaces of solar panels (Figure 3 (b)), which are arranged in the desired position. Glass pieces were placed on the yellow shelf above the solar panels as shown in Figure 3 (c) after certain period of time. Test platform in Figure 3 (c) consists of three parts. These are light source, PV panel and measurement unit. As the light source, halogen lamps are used in test platform. Technical computations of these lamps are obtained with Dialux. Main specifications of monocrystalline PV module which is used in test platform are given in Table 1.

Table 1. PV module main specifications

Properties	Value
Maximum power ( $W_p$ )	10 W
Maximum power voltage ( $V_{mpp}$ )	16.8 V
Maximum power current ( $I_{mpp}$ )	0.6 A
Open circuit voltage ( $V_{oc}$ )	21 V
Short circuit current ( $I_{sc}$ )	0.68 A

As shown in Figure 3 (d), output of system was measured with the help of developed electronic measurement device when exposed radiation using 1000 W halogen lamps. The output current and the output voltage values from the PV panel are transferred to the electronic part of the developed measurement system, as shown in Figure 3(d). This data is amplified and sent to a boost type DC/DC converter with a load. Loads are 25 ohm and 50 W resistors. After measurement process, all data are transferred to the PC or digital screen (Figure 3 (e)). Measurement and control diagram of the experimental system is given in Figure 4.

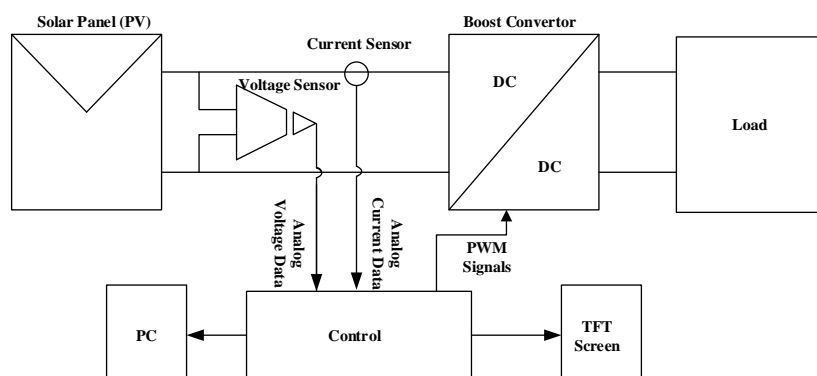
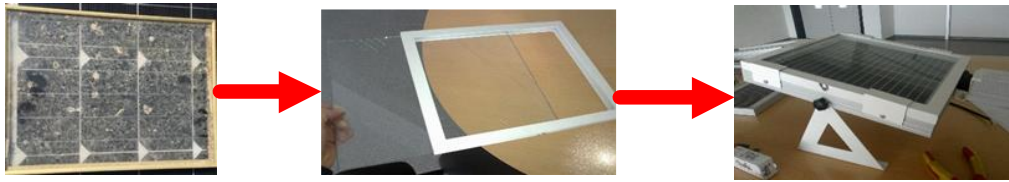


Figure 4. Measurement and control diagram of the system

## 4. Questionnaire

The developed educational kit was used by students in the practice of "Electric Power Generation, Transmission and Distribution" coded ELK201, Hakkari University Colemerik Vocational School, Electrical Program. A brief introduction was given to the students about the generation of electricity from solar energy, the components of the module and the measurement systems before the module was used. The experimental setup installed in the Solar Energy Research Laboratory, Hakkari University was used by each student. In the first step of measurement, clean glasses placed to surface of the panels and output power of panels were measured at different tilt angle.

Following this measurement, the soiled glasses, which were kept in the natural environment for a certain period of time, were mounted on the panel and changes in the output power due to soiling was measured as shown in Figure 5.



*Figure 5. Conversion from clean glass to dirty glass*

After all experimental measurement, a questionnaire including 11 questions was applied to 32 students. Intelligibility, handiness and benefits provided by the interface were questioned within the scope of the survey is given in Table 2.

*Table 2. Questionnaire*

No	Questions
1	The educational kit is easy to use.
2	The educational kit is easy to understand.
3	The educational kit is sufficient for the education of PV systems.
4	Speed of the educational kit is sufficient.
5	The educational kit is suitable for education and research.
6	The visual design of the educational kit is well prepared.
7	The educational kit helps to learn PV systems.
8	The educational kit is suitable for education and research.
9	The educational kit can be used in different courses.
10	The educational kit is sufficient for the analysis of PV systems.
11	The educational kit has flexibility as it should be.

## 5. Results and discussion

### 5.1 Case studies

Four different tilt angles were selected. These are 30°, 37°, 45° and 60°. The radiation values on the PV surfaces were measured for each tilt angle. To detect the soiling effect on PV panel output power, clean glasses are left outside in five different location (Dirty Glass1 – Dirty Glass5). Comparison of the power values obtained from PV models and outputs of PV panels is given in Table 3. Two main parameters were compared in Table 3. The change in output of the panels when changing the installation angle of the panels and the change in the output power of the panels due to pollution. All experiments in the solar energy analysis module were conducted by each student under control of lecturers. From Table 3, a reductions in power output can be seen in all dirty glasses. Additionally, tilt angle changing also affects the power outputs of PV module. Power outputs of different for dirty glasses due to the different soiling level of five different locations.

*Table 3. Results of the clean and soiled glasses*

Tilt Angle (°)	Clean Glass (W)	Dirty Glass1 (W)	Dirty Glass2 (W)	Dirty Glass3 (W)	Dirty Glass4 (W)	Dirty Glass5 (W)
30	7.23750	6.29176	6.22325	6.29176	6.29176	6.84495
37	7.44970	6.65640	6.56464	6.67850	6.58665	6.97510
45	7.53414	6.80785	6.65640	6.85233	6.74128	7.03859
60	7.21490	6.57237	6.36745	6.80418	6.67850	6.79684

## 5.2 Students' feedback

The contribution of the educational kit to the learning outcome of the course was determined by a short questionnaire study. A questionnaire including 11 questions was applied to 32 students. Intelligibility, handiness and benefits provided by the interface were questioned within the scope of the survey and the results are shared in Table 4.

Table 4. Results of the questionnaire

Question No	Number of Answers				
	Strongly agree	Agree	Undecided	Disagree	Strongly Disagree
1	13	16	3	0	0
2	14	13	4	1	0
3	9	6	13	4	0
4	7	15	9	1	0
5	11	16	4	1	0
6	11	15	1	5	0
7	11	11	8	2	0
8	11	14	7	0	0
9	3	11	14	4	0

Likert scale results, which include 11 items related to the use of the "Solar Energy Analysis Module", are given as below. It was applied to 32 students studying in Hakkari University Colemerik Vocational School Electricity program and results were analyzed by SPSS program and given in Table 5.

Table 5. Reliability Statistics of the questionnaire

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	Number of Items
0.768	0.770	11

Reliability analysis was performed to show consistency of the measurement tool of the solar energy analysis module on learning levels of students and the internal consistency reliability of the scale is shown in terms of Cronbach Alpha value as in Table 4. According to the Table 4, the reliability coefficient of the scale, which should be at least 0.70 and can be reduced to 0.60, is calculated as 0.768. This result shows that the internal consistency of the 11 items applied to students are within acceptable limits. When questionnaire is analyzed in detail (Table 3), percentage of total student who answer the question of solar energy analysis module is easy to use as agree and strongly agree is 90.625%. 84.375% of students indicated that module is easy to use. 40.625% of the students remained undecided while 46.875% positive answer was given to the question of whether the designed module can be used as a training material in solar energy education. 56.25% of the students answered that the "Solar Energy Analysis Module" was sufficient in the analysis of photovoltaic systems, however, 40.625% remained undecided. In general, solar energy module design was evaluated as successful with a value of 81.25%, however, remaining of students indicated that solar energy analysis module design was not well prepared.

## 6. Conclusions

Electrical energy production from solar energy is used to meet the increasing electricity demand by both commercial and domestic users. Therefore, experienced engineers and technical staff are needed to the design and installation of solar energy systems. Many teaching methods have been tried in order to train qualified staff. One of the most effective methods among them is learning by practicing in real life. In this study, a solar energy system module was developed and introduced to students to explain the effect of tilt angle and pollution on solar power systems output. The developed module was used by the students and the Likert scale, consisting of 11 items,



was applied to determine the achievements of the students after practice the module. Our results showed that the module can be used in technical education studies with a success rate of 84.375%. It was observed that 90.625% of student gave positive feedback about design of module. It was seen that the lowest score with a value of 46.875% was given to the question of “Solar Energy Analysis Module design sufficient for the education of PV systems” when the questions are examined. According to these results, it was realized that students want to see the effects on PV systems in real environment. Moreover, face-to-face interviews with students showed that this method is more efficient than classical teaching methods. As a result, it was concluded that developed module is appropriate to be used as a course material because the designed module is simpler and cheaper than other solar generation simulation methods and also increases the learning desire of students in education. As a future study, developed training kit can be revised to obtain I-V and P-V curves of the PV modules.

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