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Engineering education using a remote laboratory through the Internet

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An experiment using real hardware and under real test conditions can be remotely conducted by engineering students and other interested individuals in the world via the Internet and with the capability of live video streaming from the test site. The presentation of this innovative experiment refers to the determination of the current voltage characteristic curve of a photovoltaic panel installed on the roof of a laboratory, facing south and with the ability to alter its tilt angle, using a closed loop servo motor mounted on the horizontal axis of the panel. The user has the sense of a direct contact with the system since they can intervene and alter the tilt of the panel and get a live visual feedback besides the remote instrumentation panel. The whole procedure takes a few seconds to complete and the characteristic curve is displayed in a chart giving the student and anyone else interested the chance to analyse the results and understand the respective theory; meanwhile, the test data are stored in a file for future use. This type of remote experiment could be used for distance education, training, part-time study and to help students with disabilities to participate in a laboratory environment.

Keywords: solar engineering education; remote laboratory; photovoltaics; computer application; distance education

1. Introduction

Over the last years the applications of photovoltaic (PV) systems have grown rapidly in Europe and around the world. It should be noted that the installed PV power during 2008 increased significantly in many countries compared to 2007, such as in Korea six-fold, in Spain almost five-fold, in France it more than tripled as it did in Portugal (International Energy Agency 2009). These systems manage to provide electrical power directly from the sun without harming the environment and without moving parts, rendering them very attractive. Such systems can be installed in a variety of applications, not only in cities but also in areas where there is no electricity or where the costs of connecting to the power grid are prohibitively high. Being able to store the electrical energy produced by the PV panels offers a reliable, efficient and safe source of electricity day and night.

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It is well known that education on solar systems must be one of the priorities of the energy policy, to promote solar energy applications for sustainable development. It is impossible to promote successfully all the aforementioned systems without suitable educated people who will be involved in the design, sizing and installation of solar systems.

The main part of a PV system is the PV panel itself because it is responsible for converting solar energy to electricity. Thus, the theory of PV panels has been included in the syllabus of most educational institutes with an engineering studies programme. In the theory of PV panels, the study of the characteristic curve of the panel is very important because it gives important information on the electrical characteristics and is needed for the performance analysis, simulation and design of PV systems (Duffie and Beckman 2006, Mahmoud 2006, Celik and Acikgoz 2007, Ishaque *et al.* 2011). However, it is well known how important is the role of practical work in engineering education (Leach and Paulsen 1999, Colwell *et al.* 2002) and, hence, theoretical study should be combined with experimentation in order for the student to be able to apply the theory of the specific device in real test conditions. On the other hand, the technical data provided by the manufacturers of the certified solar modules at standard test conditions are insufficient to do modelling (Carrero *et al.* 2010). Also, an overestimation of the production by up to 40% was reported in comparison to the production in standard test conditions (Durisch *et al.* 2000). Therefore, knowledge of the characteristic curve of PV modules, under real operating conditions, is needed to provide a realistic assessment of their productivity (Zhou *et al.* 2007, Aranda *et al.* 2009, Duran *et al.* 2009, Chel and Tiwari 2010).

Nowadays, the traditional approach to practical sessions in real laboratories is changing and virtual and remote laboratories are gaining ground, due to developments in computer, Internet and control technology. In the virtual laboratory, each experiment is simulated by using software (Dormido 2004, Ma and Nickerson 2006), while the remote laboratory refers to the real-time Internet-based controlled experiment hardware (Scanlon *et al.* 2002, 2004). The results from comparative studies between remote and traditional laboratories have proved that they are comparable in effectiveness of learning outcomes (Nickerson *et al.* 2007). Additionally, the necessity of renewable energy education has been emphasised by many researchers (Bojic 2004, Zografakis *et al.* 2008, Jennings 2009, Acikgoz 2011, Karabulut *et al.* 2011).

The laboratory of renewable energy sources of the Technological Educational Institute of Athens has developed a series of simulated experiments for educational use (Axaopoulos *et al.* 2002, Axaopoulos and Pitsilis 2007) and has recently developed a system that can perform a real-time experiment remotely via the Internet in order to determine the characteristic curve of a 55 W_p PV panel. The panel, together with the instrumentation and automation modules, is placed on the roof of the laboratory and through a web server anyone interested can perform a live experiment (Figure 1). (The system developed is available through the following website: http://helioslab.teiath.gr/)

This way, anyone connected to the laboratory's web server can perform experiments under different test conditions and discover the different results arising from their own choices on the tilt angle of the panel and observe the resulting changes on the characteristic curve. In addition, the user could compare the experimental I-V curve with the theoretical curve for the same irradiance and panel temperature, using one of the methodologies available in the academic literature to model the PV panel.

Because of Greece's higher annual sunshine hours in comparison with other European countries, especially the northern ones, this experiment can be performed even during the winter period whereas in other countries local weather conditions are unsuitable. Classroom courses can also benefit from this system by letting the teachers demonstrate the behaviour and then analyse the characteristics of a PV panel in real conditions. Also, this type of remote experiment could be used for distance education, training and part-time study. Moreover, the remote laboratory could help students with disabilities to increase their participation in a laboratory environment.

Figure 1. The photovoltaic panel.

The aim of this paper is the presentation of a system that can be used in energy education for live and remote experimentation through the Internet. The system related to the determination of the characteristic curve of a PV panel under real weather conditions and with video coverage.

2. Characteristic curve of a PV panel

According to the PV effect, every PV panel, which usually consists of many PV cells connected in series, exposed to solar radiation produces DC voltage. PV panels are used in grid connected or autonomous systems in a variety of applications in order to supply electricity to various loads, especially in remote sites.

In order for a PV panel to be used efficiently when it is connected to different electrical loads, its electrical behaviour needs to be known. The curve that describes the PV's behaviour is known as the current-voltage (I-V) characteristic curve. The PV panels sold in the marketplace usually come with a datasheet that has a diagram with this curve. A schematic diagram is shown in Figure 2.

The voltage at the point on the diagram where the current is zero is known as the open circuit voltage (V_{oc}) and it is where the panel voltage reaches its maximum value. Respectively, the current at the point on the diagram where the voltage is zero is known as the short circuit current (I_{sc}) and it is where the panel current reaches its maximum value. It is worth mentioning that the short circuit current is directly proportional to the intensity of the solar irradiance received by the panel, while the open circuit voltage is loosely affected by the intensity of the solar irradiance received by the panel (Benmessaoud *et al*. 2010). Regarding the open circuit voltage, it can also be mentioned that it drops linearly as the temperature of the PV panel rises (Radziemska and Klugmann 2002, Nishioka *et al*. 2003).

There is a point on the I-V characteristic curve where the power of the panel is maximum, and so is the area of the parallelogram formed by the two lines drawn from the point perpendicular to the two axes and the two axes themselves. This point is called the maximum power point (Figure 2). The newly developed web-enabled system produces the power-current (P-I) characteristic curve of the solar panel as well, as shown in Figure 4.

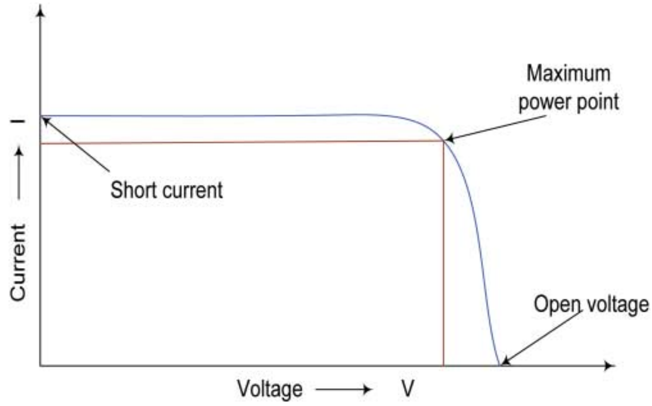

Figure 2. Schematic representation of the characteristic curve (current voltage (I-V)) of a photovoltaic (PV) panel.

3. Description and operation of the experimental device

The device, which was developed in the laboratory of renewable energy sources, consists of the following basic parts:

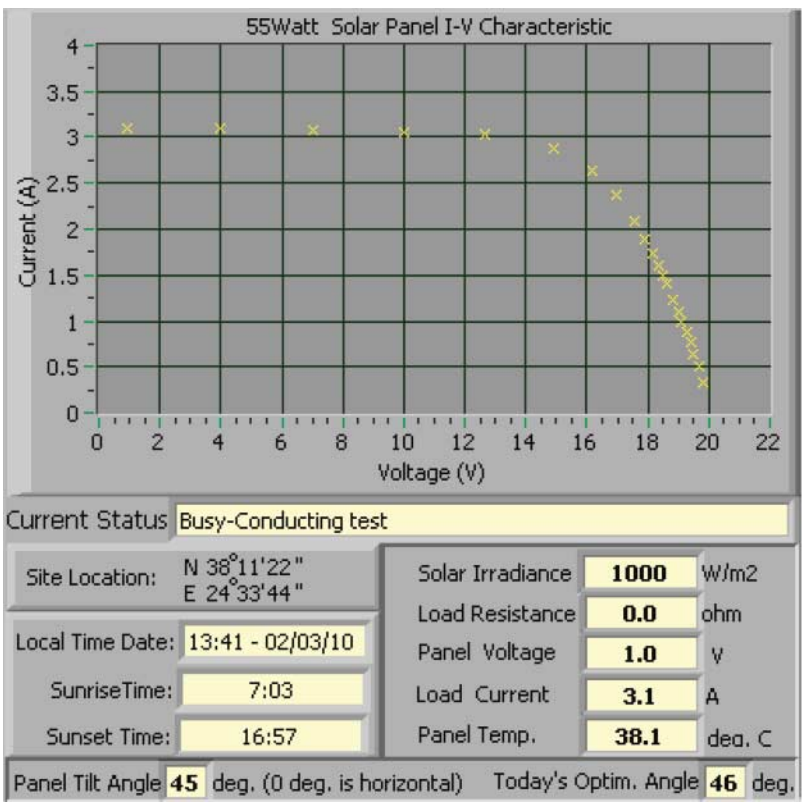

Figure 3. Screen showing the current voltage (I-V) characteristic curve and other useful information regarding the experimental conditions.

- A PV panel.
- An electronically controlled ohmic load.
- Automation and instrumentation devices.
- A web server with automation and instrumentation software.
- An outdoor web camera for live viewing of the PV panel.

The PV panel is a monocrystalline silicon type of 55 W_p, is installed on the roof of the laboratory facing south and its tilt angle can be adjusted from 0–90° with the use of a closed loop servo motor. The servo motor is attached to the horizontal axis of the PV panel. Each day, the panel is tilted to its optimum solar midday elevation angle for that day. Of course, the user can readjust the tilt angle to the value of their choice (within the specified range). On the upper part of the panel, and on the same plane, there is a pyranometer attached, to measure the total solar irradiance, while on the back of the panel's plate there is a Pt-100 probe to measure the panel's temperature. The current measured values from these probes, along with other information, are shown on the experiment's web page.

The automation and instrumentation devices are connected to the computer hosting the experiment through a twisted pair (UTP) cable in a daisy chain configuration, using the RS485 serial communication protocol. This set-up makes it possible to place the various devices at a total distance of 4000 feet from the computer. In this way, critical signals from probes and other devices can be measured and controlled locally avoiding signal loss due to attenuation on long cables. The measured signals are:

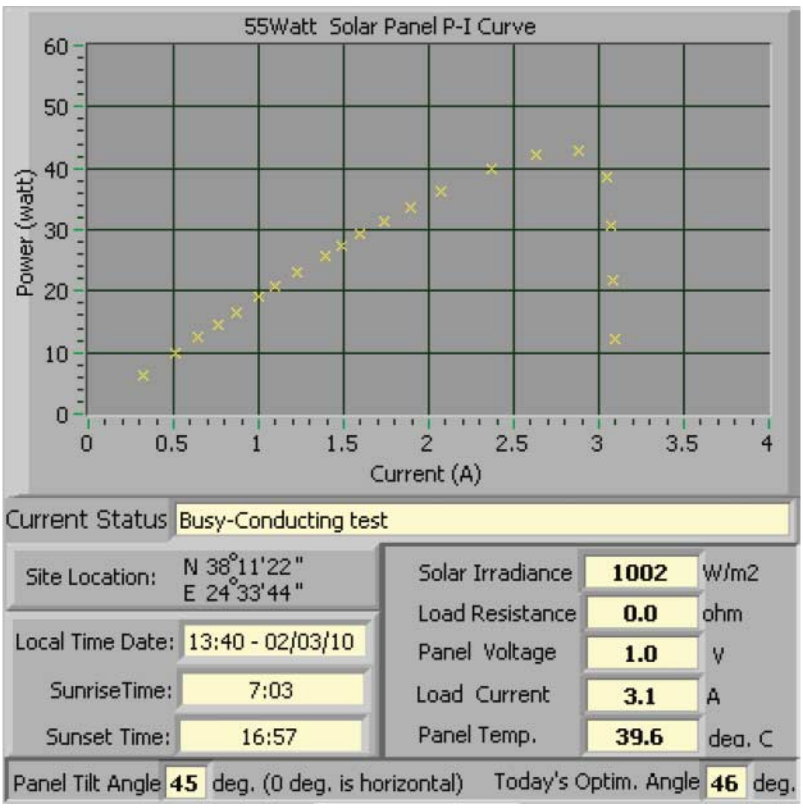

Figure 4. Screen showing the power current (P-I) characteristic curve and other useful information regarding the experimental conditions.

- the PV panel's voltage;
- the current into the ohmic load;
- the total solar irradiance on the panel's plane;
- the temperature at the back of the panel;
- the current tilt angle of the panel.

The servo motor operates on a closed loop so that the system has a feedback from the panel's angle and, most importantly, can detect a malfunction on the panel's tilt mechanism. Two conditions must be met before an experiment can begin: (a) permitting current conditions (daytime, sufficient solar irradiance); (b) the PV panel to be tilted at the desired angle. The experiment comprises the sequential application of ohmic loads (resistor combinations) of carefully chosen values, so that enough representative samples of the I-V characteristic curve are gathered. An array of fast electromechanical relays controlled by the system's software handles the many different connections required for this task. Each resistor combination is applied for a few tenths of a second and so the whole experiment does not last long enough for the solar irradiance to change within that time, and also the system can return back to its idle state ready to be used by another user. The measured values are displayed on a chart diagram (Figure 3), while for each experiment all the measured values, together with related information, such as solar irradiance, panel temperature, tilt angle and date/time, are stored in a file available to the user to download and analyse at a later time. After the completion of the characteristic curve on the diagram, a second diagram showing the power-current curve is displayed (Figure 4).

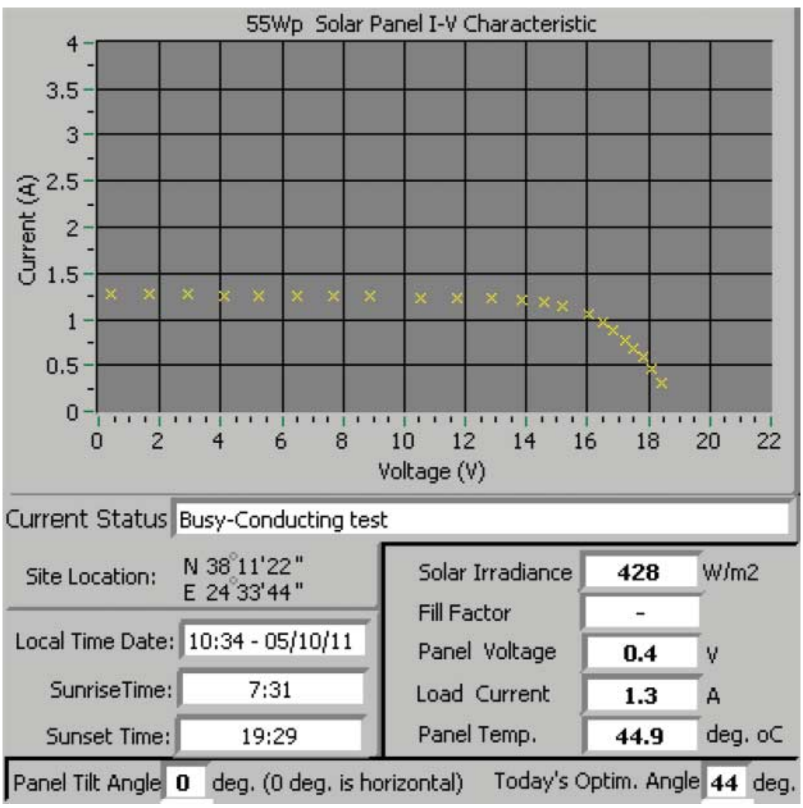

Figure 5. Screen showing the current voltage (I-V) characteristic curve for a tilt angle of 0° and other useful information regarding the experimental conditions.

The software is implemented with Labview and has a web interface allowing for remote use, where multiple users can monitor the system concurrently, but only one can control it, whoever manages first to choose and submit their choice for tilt angle. Finally, the live view from a web camera gives the user a sense of personal presence in the place where the experiment takes place.

3.1. *Application*

It is well known that the tilt angle of the PV panel affects the receiving solar irradiance, which, in turn, has an important influence on the power output from the PV panel. However, increasing the irradiance increases the electrical power generated by the PV panel, since the current is nearly proportional to the incident irradiance. The curve of the power delivered by the PV panel versus panel current is especially important when considering maximising power transferred to the panel load.

The above described effect can be easily illustrated by using the proposed remote laboratory.

At some time during the day and if the system is ready to operate, one may enter the desired tilt angle into the appropriate field and submit their request. The system will automatically adjust the tilt of the PV panel to the desired angle and this change can be seen in the next live photo from a web camera. Also, the experimental characteristic curves of current-voltage and power-current are shown on the screen and an external file containing the output data is generated.

For demonstration reasons, the remote laboratory has been used for a panel tilt angle varying from 0° to 90°. The characteristic curves and the output data of 0° are shown in Figures 5, 6 and 7

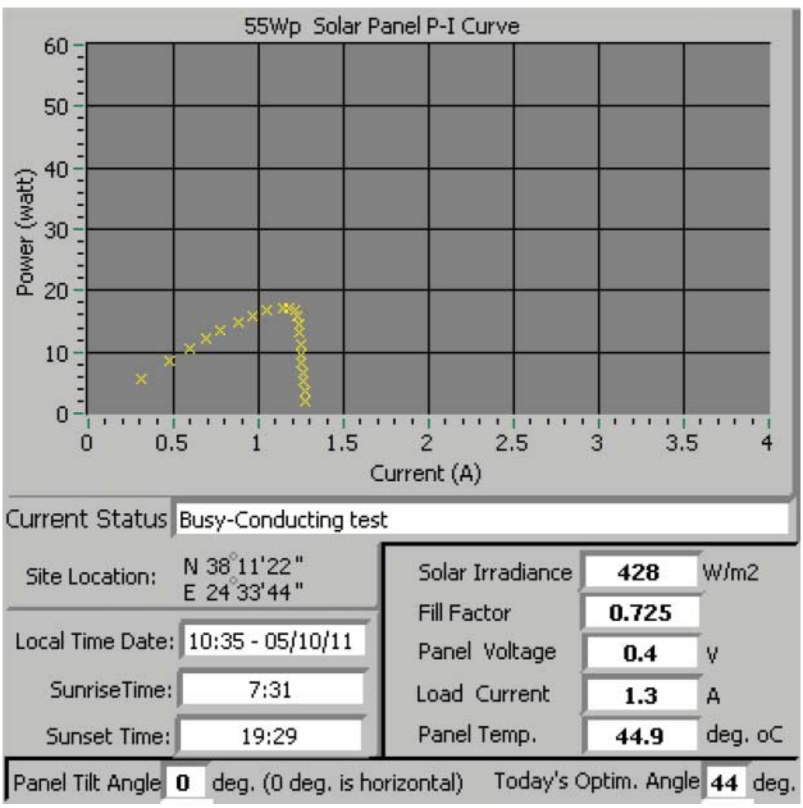

Figure 6. Screen showing the power current (P-I) characteristic curve for a tilt angle of 0° and other useful information regarding the experimental conditions.

respectively. The user can process the data from the external files and calculate the maximum electrical power for each tilt angle. The results obtained for all values are plotted in Figure 8.

Helios Lab
I-V Characteristic of a 55Wp Solar Panel tilted at: 0 degrees
Panel Temperature during experiment: 44,9 °C
Date: 05/10/11 Local Time: 10:35:36 AM
Site Location: N38:11:22 - E24:33:44

V Volts	I Amperes	Solar Irradiance W/m²
18,417	0,304	429
16,012	1,046	429
17,237	0,779	428
8,908	1,25	428
13,83	1,212	428
4,12	1,258	428
15,166	1,138	428
6,481	1,254	428
11,714	1,237	428
1,648	1,279	428
7,705	1,254	428
17,504	0,687	428
12,828	1,229	428
16,502	0,958	428
2,895	1,271	428
14,565	1,179	428
16,858	0,883	428
5,256	1,258	428
18,083	0,471	428
10,511	1,242	428
17,816	0,592	428
0,401	1,283	428

Figure 7. The data of the generated file for a tilt angle of 0°.

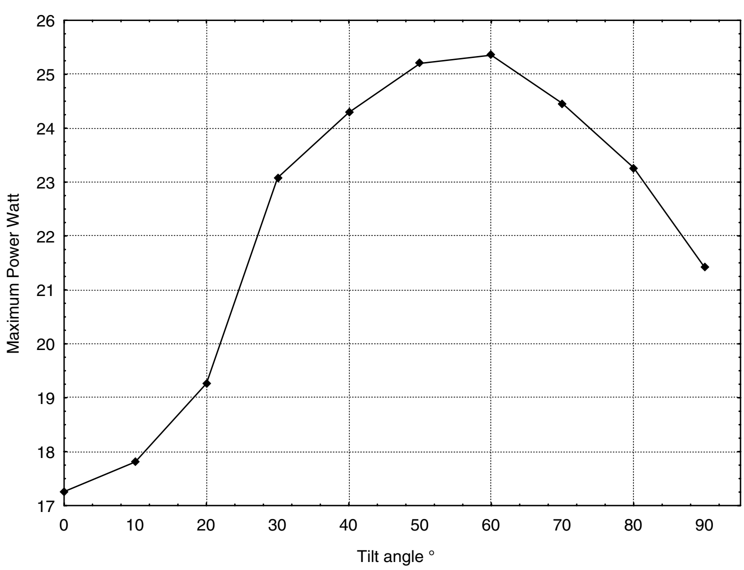

Figure 8. The maximum power output of the photovoltaic panel at different tilt angles.

It is evident that, for a specific location, season and time of day, there is an optimum tilt angle of the PV panel, which produces maximum power. In this application, the optimum tilt angle is relatively high because it is morning (10:34 hours) and the solar altitude is low.

Similar to the preceding application, the proposed system can run in real conditions for an extensive set of exercises in the engineering education sector.

4. Conclusions

The system that was developed gives the ability to perform remotely, through the Internet and, in a very short time, an educational experiment concerning the determination of the I-V characteristic curve of a solar PV panel under real conditions while at the same time the student can have a live view of the panel through a web camera.

Thus, students from around the world, whose institutes/schools do not have laboratories, or their countries do not have a high annual number of sunshine hours, can experiment in their free time and then analyse the results according to the taught theory. This approach opens new ways in the teaching and educational process and gives students the feel of an almost direct experience with the experimental device.

This experiment can be performed not only by students but also by professionals/engineers who want to familiarise themselves with new technologies.

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